

*An Agroclimatic Assessment
of
the Horotane Valley*

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Abstract

The microclimate of the Horotane Valley is characterised to enable an assessment of land-use potential in the valley. Crops that are traditionally thought of as marginal or unsuitable for commercial growth on the Canterbury Plains, can be grown successfully in the valley. While the residents of the valley have a qualitative appreciation of the climate, no quantitative data had previously been collected to characterise the microclimate.

Data collection took place over a five month period from 14th February 1995 to 31 July, 1995. Field observations of maximum and minimum temperature and short-wave radiation are augmented by modelling. Temperature data are used to determine the Growing Degree Day, chill unit and frost distribution. Continuous monitoring of the wind in the upper valley allows analysis of the diurnal and seasonal variation in the wind regime.

Radiation receipt varies with slope angle and aspect. Radiation modelling using the "Cosine Law of Illumination" produces comparatively high results as cloud cover, air pollution levels and sky view factors are not taken into account. Albedo varies with the surface colour, roughness and moisture level.

Growing degree days initially increase with elevation, until the lower maximum temperatures in the thermal belt counteract the higher minimum temperatures. Chill units decrease with elevation in the thermal belt and then increase again. Frosts are most common on the valley floor and decrease in frequency and severity with elevation up the valley slopes. A temperature inversion is most likely to develop under anticyclone conditions when the nocturnal long-wave emission is at a maximum. Nocturnal temperatures follow the normal lapse rate when the atmosphere is well-mixed. Diurnal temperatures tend to follow the normal lapse rate.

Thermotopographically generated winds are prominent in the valley wind regime. The northerly anabatic wind develops in the valley following sunrise. It

reaches peak velocity in the afternoon when backed by the low level gradient north-easterly and the sea breeze. A light southerly katabatic flow dominates the nocturnal wind regime. Gradient winds are modified by the valley topography and shelter is needed from the gradient southerly winds as they reach maximum speeds of 15 m/s. The valley is topographically sheltered from winds from an easterly and westerly direction.

Published knowledge of the climatic requirements of selected crops was used to evaluate their suitability to the Horotane Valley microclimate. The research has shown that the valley climate could support other marginal crops such as grapes and kiwifruit, and that the area planted in stonefruit could be extended.

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Chapter One

INTRODUCTION

1.1 THESIS CONTEXT

The Horotane Valley, a small valley in the Port Hills adjacent to Christchurch, boasts that it has "a lot growing for you". The residents of this valley have long recognised the unique climate and accordingly grown crops not viable on the adjacent plains. While they have a qualitative appreciation of the climate, no quantitative data has been collected to characterise the climate.

Modifications made to the local climate by topography are important when considering the siting of land-use activities. Climate remains one of the limiting factors for land-use despite attempts at modification of local climate by the use of wind machines for frost and tree planting for shelter.

Local scale variations in climate are often overlooked by those relying on data from the widely spaced network of climate stations in New Zealand. Fitzharris (1989) noted that the need for such information has become increasingly important with the rise in the conversion of extensive pastoral land to that of intensive horticultural use. With the change in land-use there has been a demand to know the viability of the local climate for selected crops. He also noted the absence of a systematic programme for the mapping of topoclimates at scales appropriate for horticulture. There have been several attempts in New Zealand to match climate characteristics and crops by mapping techniques (Hurnard, 1979; Kerr *et al.*, 1981; Turner and Fitzharris, 1986). These techniques are discussed in section 1.2.

A large portion of the upper valley still supports extensive sheep and cattle grazing. This area is of particular interest as it could retain the same climatic

advantages as other parts of the valley. This research will assess whether the land is viable for intensive horticulture and if so, which crops can be grown.

This chapter continues with an investigation into the production and use of small scale topoclimatic maps for the siting of land-use. To evaluate the climatic suitability of crops for certain locations, the radiation, temperature, moisture and wind requirements of plants are investigated. Land-use on the Canterbury Plains is presented to give an insight into the variety of crops that can be grown in the surrounding area.

1.2 AGROCLIMATIC MAPPING

The production of small scale topoclimatic land-use maps has been fairly limited in New Zealand. Hurnard (1979) considered the regional potential for growing Riesling grapes by mapping growing degree days (which represent accumulated temperatures above a threshold), frost and rainfall distributions. The data were obtained from the relevant climate stations throughout New Zealand. While the resulting maps have been criticised for being too general, they did show the potential for this technique.

Kerr *et al.* (1981) also attempted to match climatic crop requirements with data from climate stations in the lower North Island. They noted the topographically induced variation in climate around each station, but did not address this problem as they were only concerned with climate at the mesoscale.

The usefulness of small scale mapping of topoclimate was first addressed in New Zealand by Turner and Fitzharris (1986). They developed a technique to produce local scale maps by extrapolating data from nearby long-term stations, with verification from field observations. This results in maps of growing degree days that can be used to identify the appropriate land-use.

McGowan (1990) completed a topoclimatological study of Waimate during the winter months. He examined temperature and wind-flow, and the

significance of synoptic scale processes on the development of the microclimate and the ramifications for air pollution. Although the outcome was not specifically aimed at developing a tool for horticultural land-use decisions, it has the potential for such an application.

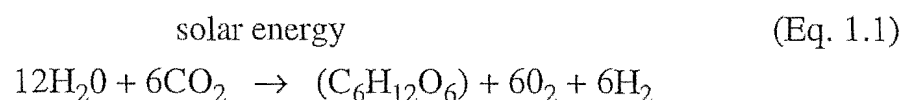
Soderstrom and Magnusson (1995) used GIS to map potential solar radiation on slopes in south west Sweden. They used a radiation index to assess potential crop growth to identify favourable growing locations. Temperature measurements were also made and analysed by kriging. This geostatistical method enables known temperatures to be extrapolated across the study area, so that areas of relative warmth or coolness can be identified. GIS was also used to model cold air drainage.

1.3 CLIMATIC CROP REQUIREMENTS

The following section introduces the climatic aspects that are important in determining crop suitability.

1.3.1 Solar radiation

The duration and intensity of short-wave radiation received at a location is important for determining growth and development rates of crops. Plant metabolism is dependent on solar radiation. Incoming radiation within the 0.4 to 0.7 μm wavelengths is termed "photosynthetically active radiation" (PAR) and is responsible for activating photosynthesis. PAR can be received in the form of direct or diffuse radiation. Photosynthesis utilises the energy provided by solar radiation to form carbohydrates from water and carbon dioxide:



These carbohydrates provide the energy for plant metabolism and growth. Radiation also stimulates other morphogenetic processes such as seed germination, stem elongation and leaf expansion. Indirectly, growth and development are affected by the balance of long and short-wave radiation at the Earth's surface because of the influence they have on both air and soil temperature, and hence evapotranspiration rates.

1.3.2 Growing Degree Days

Temperature is an important control on the rate at which biological processes take place within the plant, and hence influences the length of the growing season. Growth and development occur at an optimum rate within a certain temperature range depending on the species and its development phase.

A commonly used model to evaluate the suitability of sites for certain crops is that of Growing Degree Days or GDD. GDD assumes a linear relationship between an accumulation of heat units and crop growth and development (Tivy, 1990). This measure represents the length of time the mean daily temperature is above a certain threshold. Each crop requires a minimum amount of heat accumulation above this threshold to reach maturity during the growing season. Figure 1.1 illustrates the relationship between temperature, growing degree days and the length of the growing season.

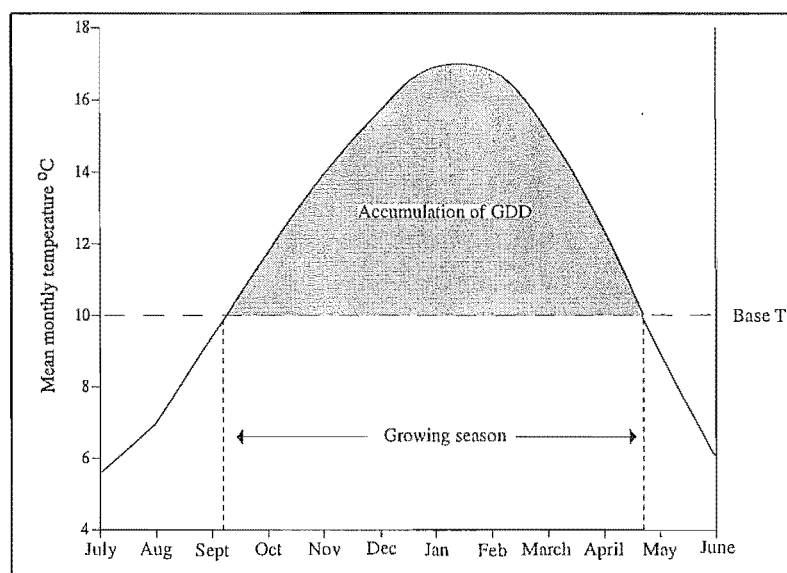


Figure 1.1 Temperature and growing degree day relationship

The required threshold is known as the base temperature, and at lower temperatures the growth and development of plants may be less than optimum or may even cease. With low GDD values the harvest date may be delayed and the crop may be subjected to frost (Turner and Fitzharris, 1986). GDD is calculated by:

$$\begin{aligned} d &= n \\ D &= \sum_{d=1} (T - B) \end{aligned} \quad (\text{Eq 1.2})$$

where D = number of degree days over a period

T = mean temperature for each day (d), calculated as the average of daily maximum (T_{max}) and minimum (T_{min}) values (°C)

B = a predetermined base temperature crop (°C), which can vary with the crop

n = number of days in the warm season.

Degree days are commonly calculated for the growing season. In New Zealand, the average degree days for 130 climate stations were calculated by the N. Z. Meteorological Service (1978). Mean monthly temperatures were assessed for the warm season of November 1 to April 30. Turner and Fitzharris (1986) used the same assessment period. The distribution of average GDD for the South Island is presented in Figure 1.2.

There are limitations to this model of assessing thermal time that must be recognised. The rate of plant growth is characteristically exponential, not linear as assumed by the model. The temperature requirements of a crop are also variable throughout the different development phases. Therefore the model fails to recognise more than one base temperature and it does not account for the diurnal temperature ranges essential for some crop growth. Despite these difficulties, this linear model of GDD does give a reasonable first approximation of where certain crops can be grown.

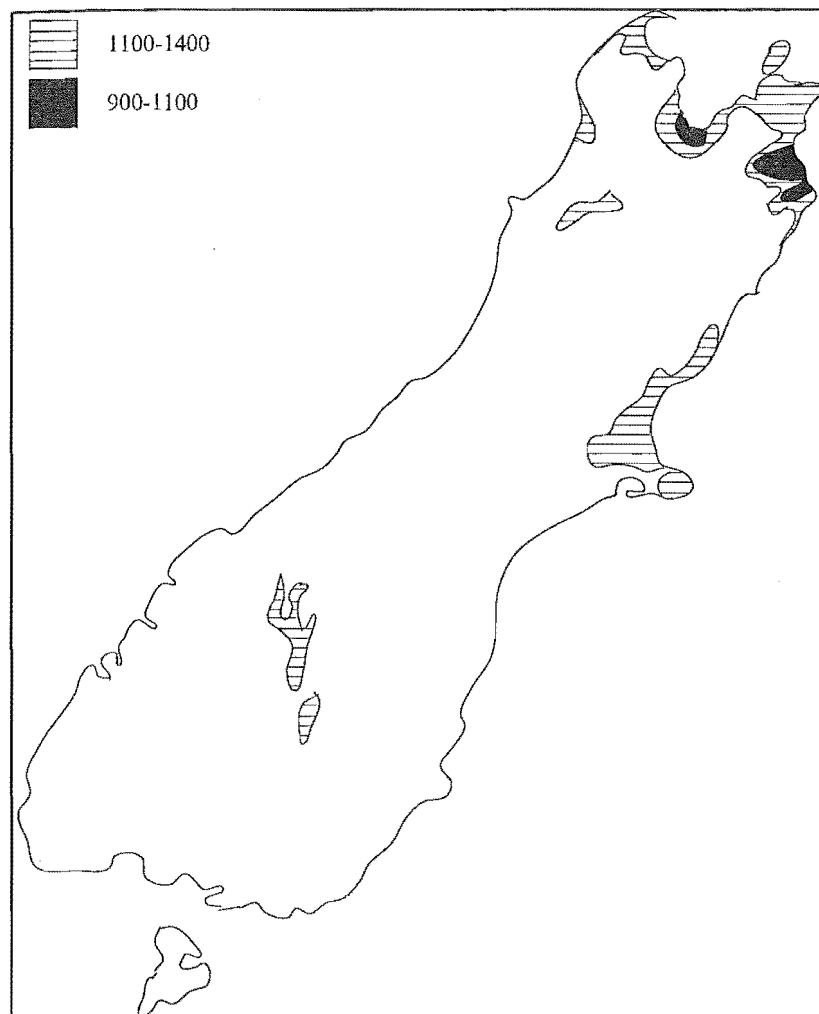


Figure 1.2 Growing degree day distribution in the South Island

(Source: Hurnard, 1982)

1.3.3 Chilling

While periods of accumulated heat are important for the growth and development of plants, so may be periods of cold temperature. Similar to modelling GDD, chill units can be calculated to express the period when the temperature is below the required threshold. The average chill unit accumulation for the South Island is presented in Figure 1.3.

Winter chilling is essential for deciduous fruit trees to break bud dormancy, and initiate the flowering process. Crop yield can be reduced as a consequence of insufficient winter chilling. This is because the buds remain dormant so the whole process of development from bud break to fruit growth and ripening is delayed. Consequently, buds may drop or blossom erratically,

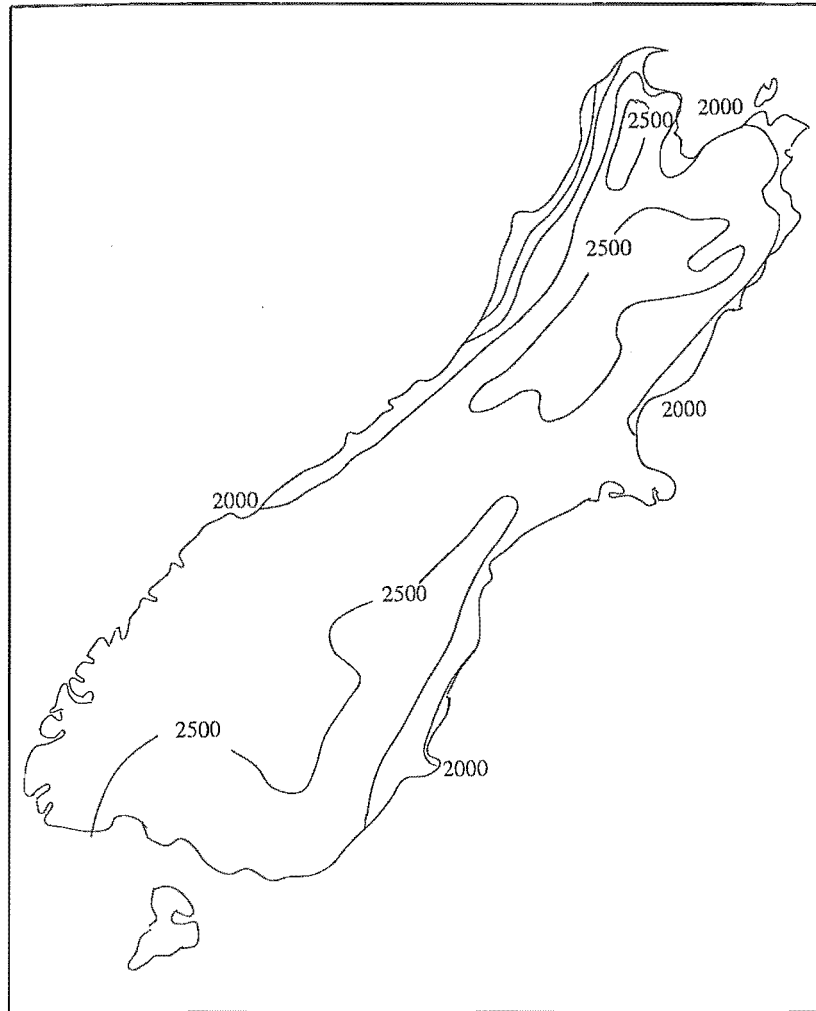


Figure 1.3 Chill unit distribution in the South Island

(Source: Kerr *et al.*, 1987)

with irregular fruit growth and ripening (Hewitt, 1973).

A technique for estimating chill units was formulated by Richardson *et al.* (1974). Referred to as the Utah chill unit model, it assigns a value or chill unit to each hourly temperature. One chill unit represents one hour at the optimum temperature for chilling requirements. The model was derived from research from deciduous fruit trees, where the optimum temperature has been defined as 6°C. Fluctuations about this mark result in lower chill unit accumulation. As Table 1.1 and Figure 1.4 show, temperatures less than 1.4°C and between 12.5 and 15.9°C, are not assigned any portion of a chill unit, while those above 16°C receive negative values and therefore reduce chill unit accumulation.

Table 1.1 Temperature criteria for chill units

(Source: Richardson *et al.*, 1974)

Estimated hourly temperature (°C)	Chill unit
< 1.4	0.0
1.5 - 2.4	0.5
2.5 - 9.4	1.0
9.2 - 12.4	0.5
12.5 - 15.9	0.0
16.0 - 18.0	-0.5
> 18.0	-1.0

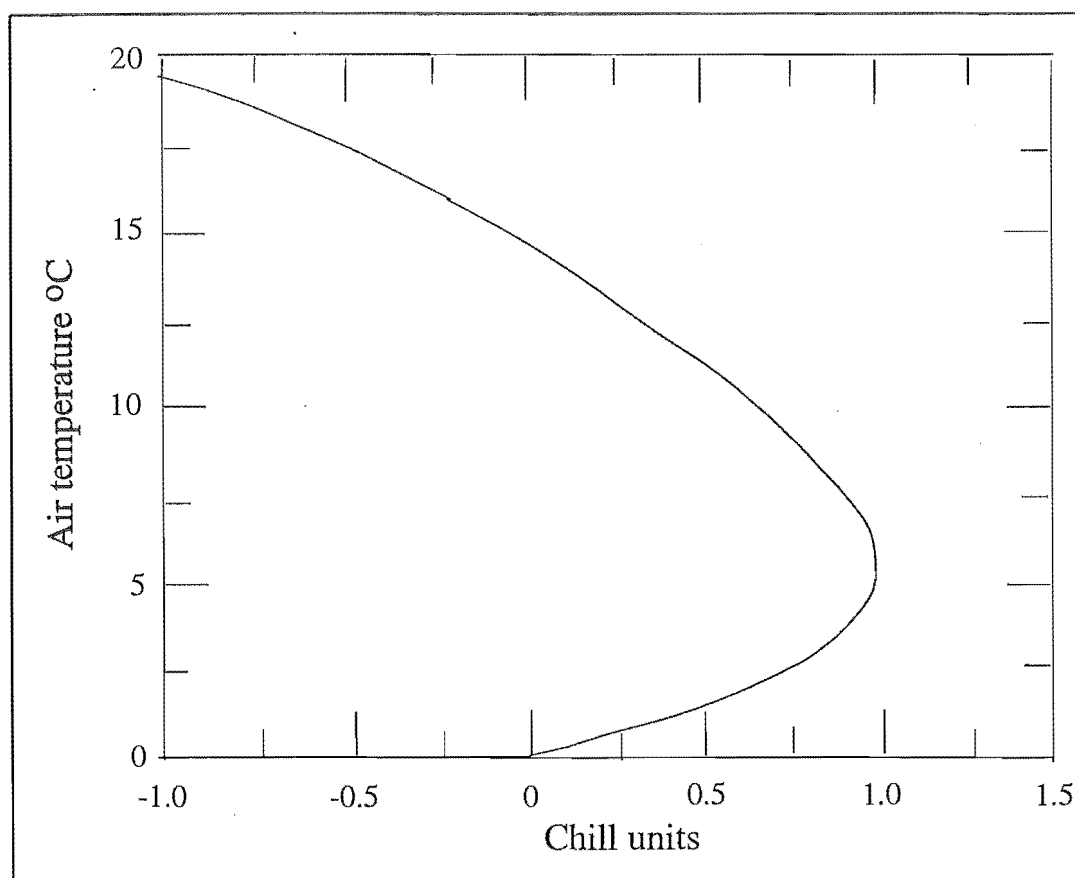


Figure 1.4 The Utah Chill Unit model

(Source: Richardson *et al.*, 1974)

To estimate hourly temperature from the available maximum and minimum data, a linear interpolation was made between the maximum and minimum temperatures. While this linear expression of diurnal temperature variation has limitations for the changeable maritime climate in Christchurch, it is a widely used method that provides a reasonable approximation.

1.3.4 Frost

Although a period of low temperature is essential for some plants, temperatures that fall below freezing can be a hazard. An air frost is defined as the condition that exists when the screen temperature falls below 0°C. A ground frost occurs when the grass temperature falls below -1.0°C (Ryan, 1987). Frost is commonly cited as the climatic aspect most hazardous to successful cropping so the growing season of many crops is determined by the last spring and the first autumn frost (Young, 1971).

Frosts can be caused by two different processes - advection and radiative cooling. Advection frosts occur when a very cold, dry air mass blows into the region bringing sub-freezing temperatures. Advection frosts are rare occurrences in Canterbury. In this region radiation frosts are more frequent, occurring in autumn, winter and spring. These develop at night as a consequence of surface radiative cooling. A clear, calm and dry atmosphere is most conducive to the development of a radiation frost. Ground frosts are common in the winter months in Christchurch (18 days in June, 19 in July and 17 in August). Of the 89 average ground frosts each year, 37 will also be air frosts (McGann, 1983).

Fortunately by winter, the frost sensitive crops, such as apricots, have entered their dormant phase and are less susceptible to frost damage. It is the spring frosts that have the potential to do the most damage. In the case of fruit trees, with each stage of development from bud burst to fruit growth, the susceptibility to frost increases (Hewitt, 1973). Ice may form on the inside (intracellular) or outside (extracellular) of the cell wall during a frost. While plants can often survive extracellular freezing, during intracellular freezing,

the ice can cause mechanical destruction of the plant. The extent of frost injury depends on the duration and intensity of the frost, and the hardiness of the plant. Stone fruit are more susceptible as they have only one or two seeds, so any damage to them can cause fruit drop. Conversely, pip fruit have a higher number of seeds and can survive if a proportion of them are destroyed (Hewitt, 1973).

Hewitt (1973) noted the importance of temperature and airflow surveys when looking to site new orchards in frost susceptible areas. Early blossoming and frost susceptible plants should be planted on the higher slopes, with later and more frost resistant crops on the intermediate slopes. Sites with the greatest frost risk could grow apples and pears.

1.3.5 Soil temperature

Soil temperature is an important variable because of its influence on seed germination and root development and therefore, the rate and duration of growth (Chang, 1971). The heat capacity of soil is greater than that of air, so it does not exhibit the same extremes in temperature. The soil temperature can be the determining factor in climatically marginal areas.

1.3.6 Soil Moisture

Water is needed to transport nutrients around the plant and to help maintain water levels reduced by evapotranspiration. The ideal soil moisture condition is termed the field capacity. This is the level needed for maximum growth and development. Too little water will lead to wilting and eventual plant death. However, excess water is also undesirable. The soil may become waterlogged causing the development of anaerobic conditions. This provides a favourable environment for bacteria and disease, the occurrence of which may lead to root rot.

1.3.7 Wind

Wind may be responsible for physical damage to a plant or deformation of its shape. Strong north-west and south-west winds are a problem on the Canterbury Plains. The wind also has a secondary effect on the temperature and humidity of the air, for example, the north-west wind causes a rise in temperature and a drop in humidity. Wind can alter the water balance of a plant by increasing evapotranspiration rates.

1.4 LAND-USE IN CANTERBURY

This research will assess how the climate of the Horotane Valley is different to that of the surrounding Plains, and the implications this has for land-use. To enable a comparison of land-use between the valley and its surrounds, a brief introduction to land-use on the Plains is presented below.

The climate and soils of the Canterbury region have long provided a favourable environment in which to farm. The plains were transformed in the early years of European settlement, from swamp, tussock grasslands and forests to extensive areas of cereal and grain. The gentle slope of the land, coupled with fertile soils and the warm, dry growing season, give the region many climatic advantages over other parts of New Zealand. Land-use has become more intensified and diverse with the development of irrigation schemes and the planting of shelterbelts.

Although drought is a limiting factor for the agricultural potential of the region, irrigation development has reduced the risk of water shortages. The dryness of the climate is in fact an advantage in terms of providing unfavourable conditions for the spread of pests and disease. Other climatic hazards in Canterbury include the desiccating north-west wind and the late spring and early autumn frosts.

The open expanse of the Canterbury Plains remains the largest producer of wheat (67% of land planted in wheat in New Zealand), barley (60%) and oats

(47%) and is also a comparatively large producer of outdoor vegetables (23%) and berryfruit (32%) (New Zealand Statistics - 30th June, 1992). More specific examples of the percentage of certain crops grown in Canterbury are presented in Table 1.2. The Horotane Valley makes up approximately 30% of the land planted in apricots in Canterbury, 23% of plums and 10% of the celery.

Table 1.2 Percentage of New Zealand crops produced in Canterbury
(Source: Statistics New Zealand, 1994)

Crop	% of New Zealand
Green beans	60
Peas	63
Celery	16
Marrow	24
Silverbeet	19
Indoor tomatoes	12
Apricots	6
Cherries	6
Plums	7
Blackcurrents	60
Raspberry	44

1.5 THESIS OBJECTIVES

The Horotane Valley has long been recognised as a producer of early, late and frost sensitive crops. While the residents of the valley have developed an understanding of where certain crops can be grown, no data exist that characterises the microclimate of the whole valley. This thesis has the objectives of characterising the microclimate of the Horotane Valley and assessing whether the land-use in the valley is optimising the potential. The microclimate is studied using field measurements taken over a five month period with interpolation and modelling providing additional information. Once the microclimate is determined, published knowledge of the climatic requirements of crops is used to assess the land-use potential of the valley.

1.6 THESIS FORMAT

Chapter Two details the physical setting of the Horotane Valley and the methodology used to collect climate data. Firstly, a climatic overview of Christchurch and the Canterbury Plains is presented. A detailed description of the soils of the Horotane Valley follows. Past and present land-use in the valley is then discussed to give an insight into the types of crops that have been successfully grown. Finally, the field methodology is described.

Chapter Three presents an evaluation of the short-wave radiation budget in the Horotane Valley. Measurements of short-wave radiation taken in a series of case studies are combined with short-wave radiation modelling to give an approximation of the short-wave radiation budget of the valley.

Chapter Four investigates the thermal regime of the valley. Growing Degree Days and chill units are calculated from data acquired in the field and augmented by statistical modelling, to produce maps of their distribution. The controls over minimum temperature distribution in the valley are investigated, with a frost risk map as an outcome.

Chapter Five illustrates the spatial and temporal variation in the wind regime of the Horotane Valley. A comparison with the Bromley and Christchurch Airport climate stations enables evaluation of the influence of topography on the valley wind regime.

Chapter Six examines the synoptic and mesoscale controls on the temperature distribution in the Horotane Valley. Three case studies demonstrate the controls on the development of a temperature inversion, the normal lapse rate and the severity of a frost event.

Chapter Seven draws together the microclimate findings to investigate possible land-use options for the valley. The suitability of grapes, kiwifruit and stonefruit is appraised by consultation of the results.

Chapter Eight summaries the techniques used during the course of the thesis to evaluate the microclimate and land-use potential. Finally, suggestions for future research are given.

Chapter Two

PHYSICAL SETTING AND METHODOLOGY

2.1 INTRODUCTION

The Horotane Valley is a small, north facing valley of approximately 150 hectares, in the Port Hills of Christchurch (Figure 2.1). It overlooks the Canterbury Plains, Pegasus Bay and the Southern Alps (Plate 2.1). The valley is part of Banks Peninsula, the erosional remnants of the now extinct Lyttelton and Akaroa volcanoes. Horotane Valley has a wide floor with north-east to north-west facing sides, that range from 10° on the lower slopes to 45° on the upper slopes. Intensive horticulture and orcharding take place on the valley floor and lower slopes, with sheep and cattle grazing on the upper slopes of the valley.

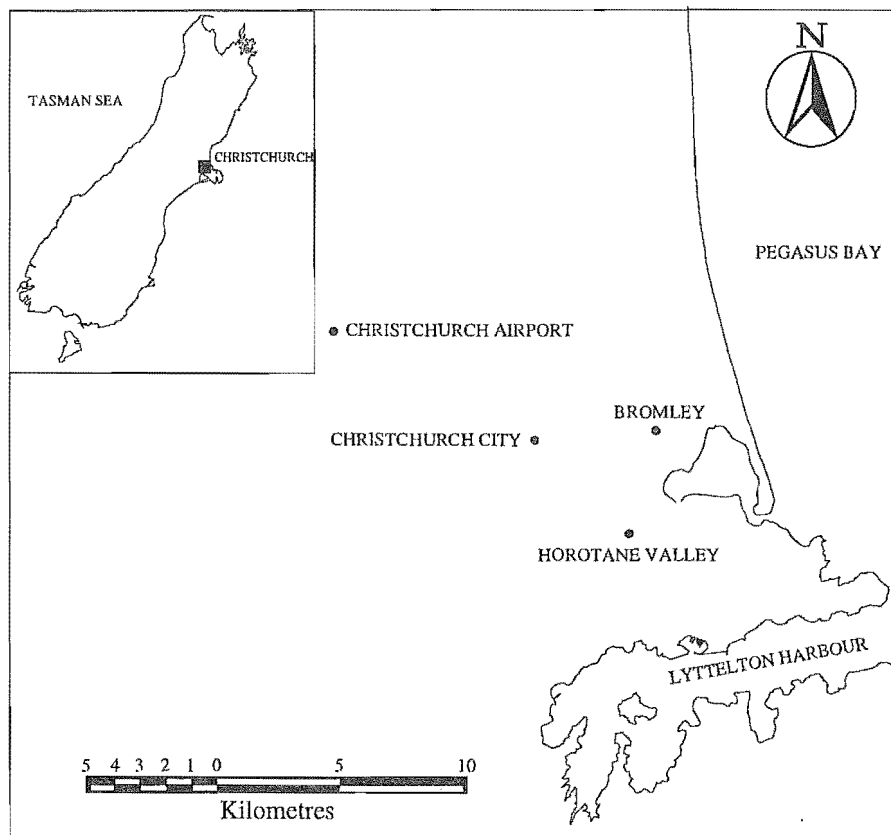


Figure 2.1 Location of the Horotane Valley



Plate 2.1 The physical setting of the Horotane Valley from the a) plains and the b) ridgeline

This chapter outlines the physical setting of the Horotane Valley and the field methodology. A brief climatology of Christchurch and the Canterbury Plains is put forward to establish the general climatic setting. Secondly, the soils of the Horotane Valley are described and their productivity, moisture status and erosion status are evaluated. An account of the past and present land-use in the valley is presented to establish the types of crops that can be successfully grown. Finally, the methodology and approaches used to obtain data in the field is outlined.

2.2 CLIMATE OF THE REGION

Although there has not been much documentation on the climate of the Port Hills, there are some well-known generalities. The climate is different to that of Christchurch and the Canterbury Plains because it is exposed to and sheltered from various elements. For example, northerly winds usually reach higher speeds on the Port Hills, as these winds are accelerated up the slopes. However, the valleys and slopes of the Port Hills are sheltered from southerly and easterly winds.

Research undertaken in the 1980's lead to a greater understanding of the wind climate of the Canterbury Plains (Sturman & Tyson, 1981; McKendry, 1983, 1985; McKendry *et al*, 1987). Figure 2.2 illustrates the variable wind climate of the region. The north-east winds are more frequent in summer, and are stronger and blow for a longer duration than in winter. This is because they are reinforced by sea breezes during the daytime. The other prevalent wind direction is from the south-west quadrant. It most frequently arrives from 210° and 240°, with each equally represented in the summer months. As the north-east becomes less prevalent toward winter, the frequency of the south-west increases correspondingly. The north-west wind also exhibits seasonal variation, with the maximum frequency occurring in late spring. Although north-westers only blow for 3% of the year, they are particularly associated with the highest temperatures and evaporation rates. It is interesting to note that although Christchurch is subject to strong south-west winds in the winter, it is the season with the highest frequency of calm conditions (24% in winter compared with 12% in summer, 14% in spring and 19% in autumn) (McGann, 1983).

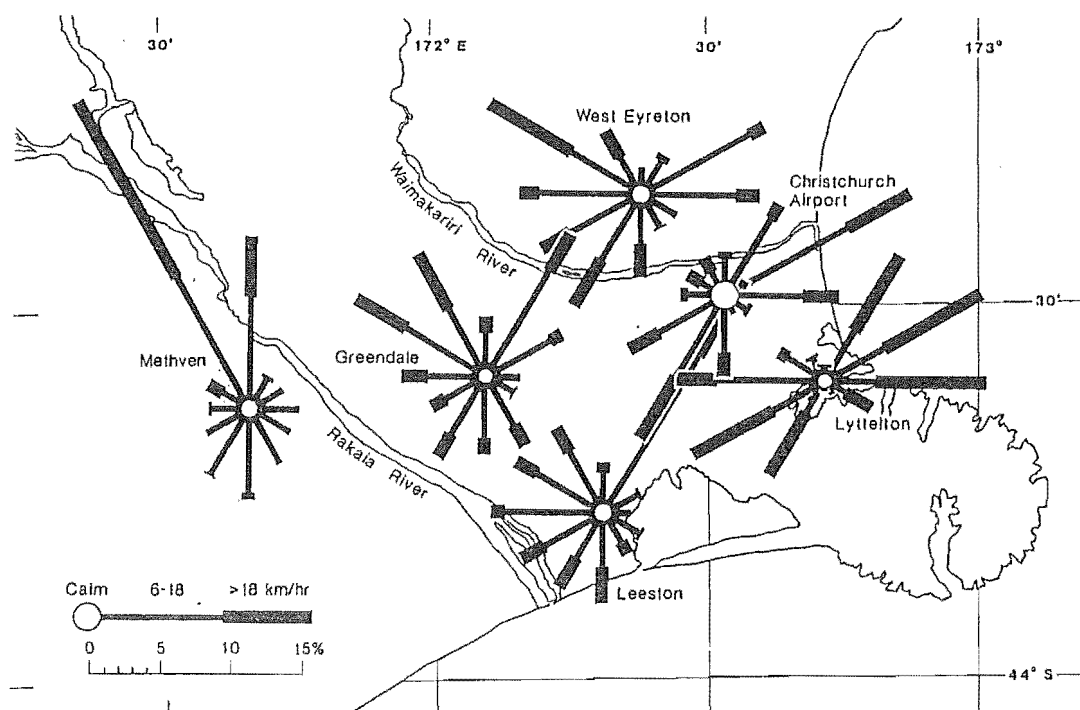


Figure 2.2 Wind climate of the Canterbury Plains during spring and summer

(Source: Ryan, 1987)

Christchurch is noted for having a relatively low rainfall when compared with the rest of New Zealand. It is sheltered from the incoming south-east and north-west rain by Banks Peninsula and the Southern Alps respectively. The primary rain bearing wind comes from the south-west. Winds from this quarter blow for only 20% of the time, but are responsible for almost half of the annual rainfall (McGann, 1983). There is also a rainfall gradient in Christchurch, with a maximum in the south-west decreasing to a minimum in the north-east (Figure 2.3). This corresponds to the most frequent directions of the rain bearing winds. Not only does more rain fall near the Port Hills, but there is also an increase in rainfall with elevation. Christchurch has an elevation of about 7m above sea level and receives 650 mm/yr, while the Summit Rd that runs along the top of the valley is at 380 m and receives 1000 mm/yr (Griffiths, 1974). Rainfall normals derived from the Horotane Valley put the yearly total as 709 mm, with an average of 51 mm/month over the summer period (N. Z. Met. Service, date unknown). The south-west is not the only wind that brings rain. Occasionally heavy rain is received from strong, moist easterly winds. Mist and cloud may also come from this quarter, to blanket the ridges of the Port Hills (McGann, 1983).

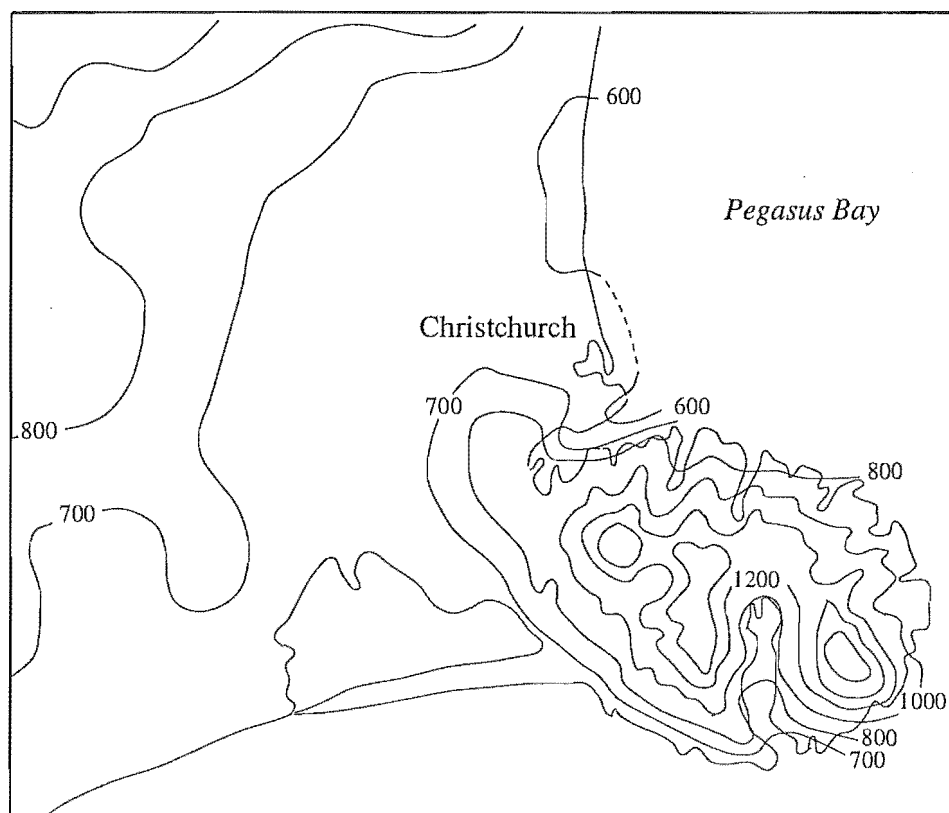


Figure 2.3 Isohyets of mean annual rainfall (mm) 1941-70

(Source: McGann, 1983)

Snow is often received at high altitudes on the Port Hills. Although it is very rare for Christchurch to receive severe snowstorms, snow falls on average three days a year (McGann, 1983). Hailstorms occur most frequently between October and March. This coincides with the growing season which is why they are so potentially devastating. Each year there is an average of six days with hail (McGann, 1983).

The warmest month of the year is January, with a mean daily maximum of 21.4°C. July is the coldest month, with only a 10.2°C maximum (McGann, 1983). The maximum daily temperatures are depressed in summer by cool sea breezes. Figure 2.4 shows the mean temperature distributions derived from temperature normals for 1951 to 1980 (N. Z. Met. Service, 1983). There is an average of 89 ground frosts in Christchurch each year being common in the months of June, July and August (McGann, 1983). They are generally radiation frosts, which occur on clear, calm nights. Frosts are less likely to occur close to the hills, or on the slopes of the Port Hills because of katabatic airflows which mix the air.

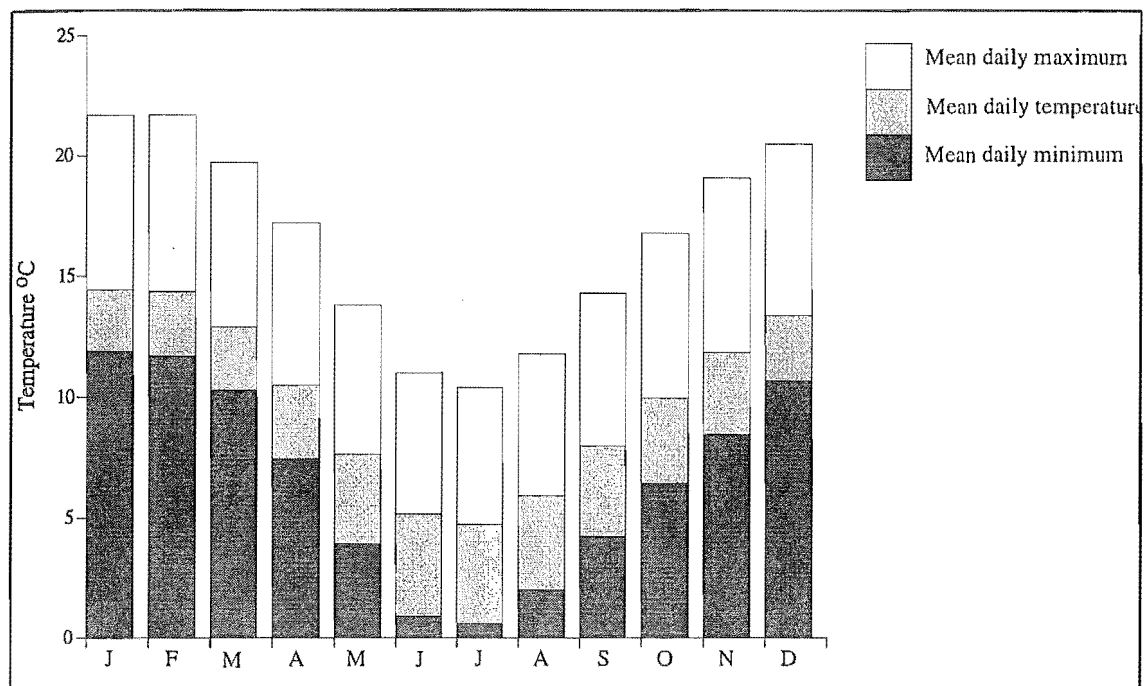


Figure 2.4 Mean monthly temperature for the Christchurch Airport, 1951-1980
(After: N.Z. Met. Service, 1983)

2.3 SOILS OF THE HOROTANE VALLEY

2.3.1 Soil classification of the Horotane Valley

The soils of the Port Hills have been classified and described by Griffiths (1974) and Trangmar and Cutler (1983). Griffiths described the structure and composition of the soils, their draining capacity and their origin while Trangmar and Cutler mapped the area in further detail. A soil map was also compiled by the Canterbury United Council (1986) which draws on descriptions from both the above references to produce a soil map of the valley (Figure 2.5).

The valley floor is largely composed of Horotane silt loam. This alluvial soil is formed from loess and basalt that has been eroded from the valley sides. It is moderately fertile but is very slow draining and tends to become waterlogged. The erosion risk is only small, due to the low angle of the valley floor. At present the soil is used for market gardening, intensive grazing and glasshouse production.

Horotane silt loam grades into Heathcote silt loam higher up the valley, where the sides of the valley rise from the floor. Griffiths (1974) identified Heathcote silt loam as being moderately well drained and slightly susceptible to soil creep and sheet erosion. In Horotane the soil is used for market gardening and orcharding as it is moderately fertile.

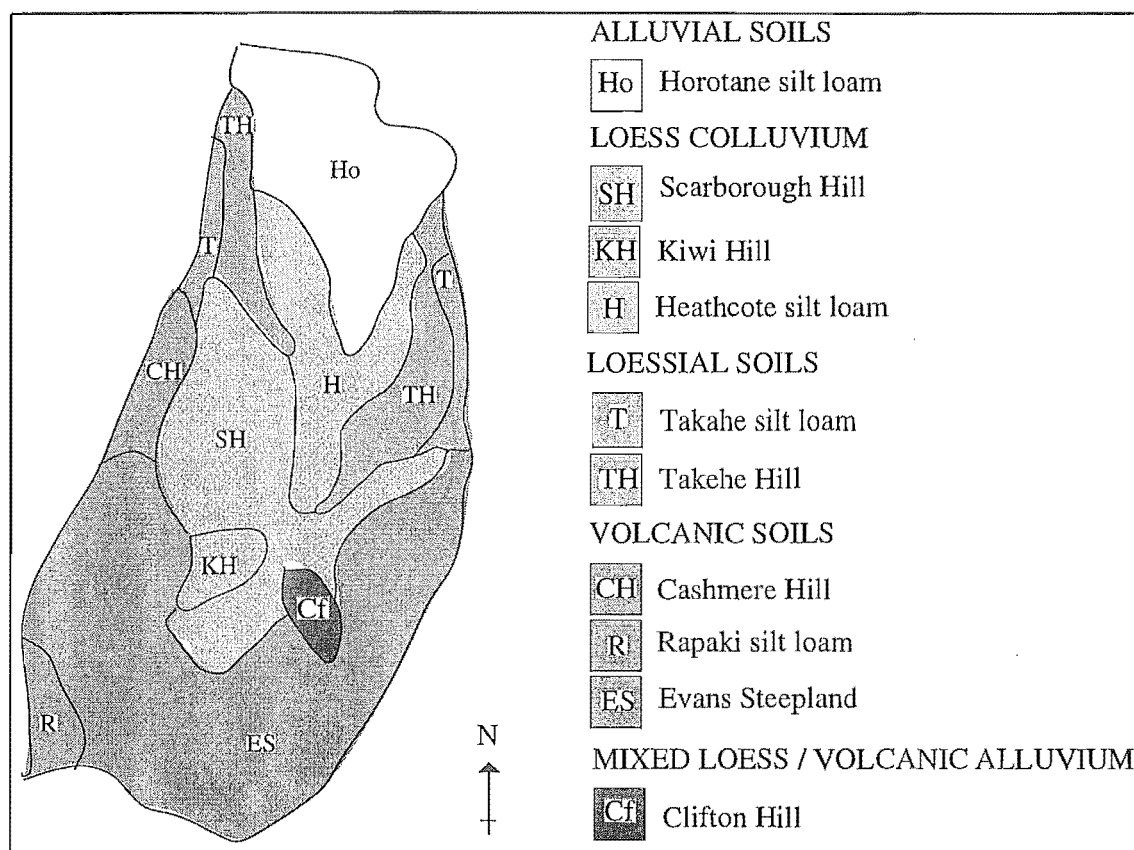


Figure 2.5 Soils of the Horotane Valley

(After: Canterbury United Council, 1986)

On the shoulders of the valley is the loessial Takahe hill soils. Due to their northerly aspect, the Takahe series suffer from moisture deficiency between January and April when evaporation rates are high. Trangmar and Cutler (1983) noted the internal drainage of these soils was very slow, and that the vertical movement of water is impeded by the internal structure of the soil. As was noted in the field, the Takahe soils become quickly waterlogged over winter because of their low field capacity. The soils are prone to tunnel gully and sheet erosion due to their structure and composition. In the Horotane valley, this soil is used mainly for grazing sheep and cattle, orcharding and intensive market gardening. Land-use options must be considered carefully on the Takahe soils, because of

the susceptibility to different kinds of erosion.

Takahe silt loam occurs higher along the ridge of the valley shoulders. They have the same general characteristics as the Takahe hill soils mentioned above - with erosion and moisture retention problems. In summer, wind erosion of the soil surface can become a problem on unvegetated land.

Scarborough hill soils make up most of the middle west side of the valley and a smaller portion of the eastern side. Internal drainage is similarly slow compared with the other soils in the upper valley but the overall drainage was described as moderate. Scarborough hill soils are composed of 10% eroded volcanic matter and redeposited loess. This loess colluvium has a layered structure that provides failure planes for erosion. The soils are not only subject to tunnel gully erosion, but also to mass movement. Tunnel gullying mostly occurs on the north-west facing slopes, whereas debris flows occur in association with seepage zones. This soil is subject to rock fall from the volcanic outcrops above.

Kiwi hill soil is found on the western slope toward the head of the valley in association with Scarborough hill soils. It has loess colluvium basaltic stones, gravels and boulders incorporated into it. The topsoil is weakly developed and prone to summer drought. The soil is susceptible to sheet wash, tunnel gullies and debris flow. Trangmar and Cutler (1983) noted the vegetation cover is often thin where sheet wash has left subsoils with a low nutrient status exposed.

Outcrops of volcanic rock are present on ridge summits and shoulders where the loess has been eroded. The Cashmere hill soils contain such outcrops. They are found on the western side of the valley, above the Scarborough hill soil and between Takahe and Evans steepland soils. Cashmere hill soils are derived from the in situ weathering of the volcanic rock. The drainage and moisture holding capacity of these basaltic soils are better than the surrounding loessial soils. Griffiths (1974) noted these soils tend to remain moist for longer and below wilting point for less time than the Takahe soils. The nutrient status of the soil is also better because of the mineral richness of the parent material.

The remainder of the upper valley is composed of the shallow, volcanic Evans

steepland soils. Compared with Cashmere hill soils, Evans steepland as the name suggests, occurs on steep back slopes instead of hilly terrain. It is a volcanic colluvium, formed on a base of weathered or weakly weathered volcanic rock, and contains only about 10% loess. In the Horotane Valley, there are a number of cliffs and outcrops protruding from the soil. Run-off from these steep slopes is rapid, with medium internal drainage but an overall excessive drainage. This results in sheet erosion where vegetation is sparse. Mass movement by debris flow and avalanche is also a risk. In the Horotane Valley, extensive sheep and cattle grazing is the only land-use on this soil type.

Clifton hill soil is a mixture of loess colluvium and volcanic colluvium. It is confined to a small section of the eastern valley side, between Scarborough hill soil and Evans steepland soil. It has imperfect and slow internal drainage and is subject to slips. It is also prone to tunnel gully, sheet erosion and soil creep.

Rapaki silt loam is a volcanic soil, that is found high up in the valley, next to the Summit Road. The soil is formed from basalt, loess and colluvium and is relatively free draining. This soil is higher up in the humid zone and it has been noted that the soil moisture is above field capacity for March to September but below it for October to February. Erosion is only slight, being mostly slip erosion.

2.3.2 Soil productivity

The main problem relating to soil productivity is not so much the nutrient status of the soil, but its moisture holding capacity. The problem is amplified on northerly aspects and on Takahe soils where the soil characteristics and high evaporation rate are unfavourable for moisture retention in the soil. The soils of the Port Hills are generally fertile, with soils of basaltic origin having a higher natural fertility than those derived from loess. The slopes of the Port Hills have traditionally been divided into humid and sub-humid zones on the basis of rainfall records. The nutrient status of the humid zone is thought to be lower, as more leaching would take place.

2.3.3 Soil stability

Soil stability is one of the most important factors that must be considered when determining land-use. Most of the soils of the Horotane Valley are prone to erosion of varying types and degrees because of their moisture retention abilities and the slope. Also as was noted above, most of the soils in the valley have poor drainage and become easily waterlogged. These are conditions that increase the erodibility of the soil. Initialisation of erosion events is caused by variations in intensity, duration and frequency of heavy rainfall events.

There are many types of soil erosion that occur in the valley. Tunnel gullying is one of the dominant erosion types, and is easily seen on the pastoral land in the valley (Plate 2.2). It occurs on loess or loess colluvium soils, such as the Takahe



Plate 2.2 Tunnel gully erosion on the north-west facing slope of the valley

series, Scarborough and Kiwi hill soils and the Heathcote silt loam. The tunnels that result undermine roads and buildings and can be hazardous to stock. The other most noticeable form of erosion is slipping on sparsely vegetated land, on the higher, steep sides of the valley. Appendix 1 contains an analysis of the suitability of the soils for urban and pastoral land-use.

2.4 LAND-USE IN THE VALLEY

The potential of the Horotane Valley for orcharding and market gardening was recognised early this century by J. F. Scott, who was responsible for the development of much of the area. The valley had previously been used for grazing sheep and for military purposes. The bottom half of the eastern flank is known as Butts Valley. This site was not only used by the Canterbury Rifle Association for target shooting, but between 1890 and 1894 it was the location of a Defence Department Camp. The land was later acquired by the Government in 1898, divided into small lots and sold to working class people (Ogilvie, 1978). A few of the original houses still remain.

The development of the valley did not really begin until Scott took hold of the land in 1910 (Kennelley, 1949). His interest in horticulture provided the impetus to build a road up the middle of the valley and sell off land in the lower valley as likely sites for market gardens and orchards. Plate 2.3 shows the valley soon after subdivision and the first plantings began. Many modifications had to be made to the land before it was suitable for such land-use practices. Hillsides had to be "broken in" which involved rocks being levered and blasted out, terraces created, tunnel gullies blocked up and filled and shelter established (Ogilvie, 1978).

The main limitations to the successful establishment of some land-uses were the erosion risk on the steeper slopes and the availability of water. The moisture deficit is not only a problem for those directly involved in growing plants, but also to the farmer concerned with the amount of food available for the grazing animals. Sheep are able to withstand drought more effectively than cattle, and are also more suitable on the less stable soils.

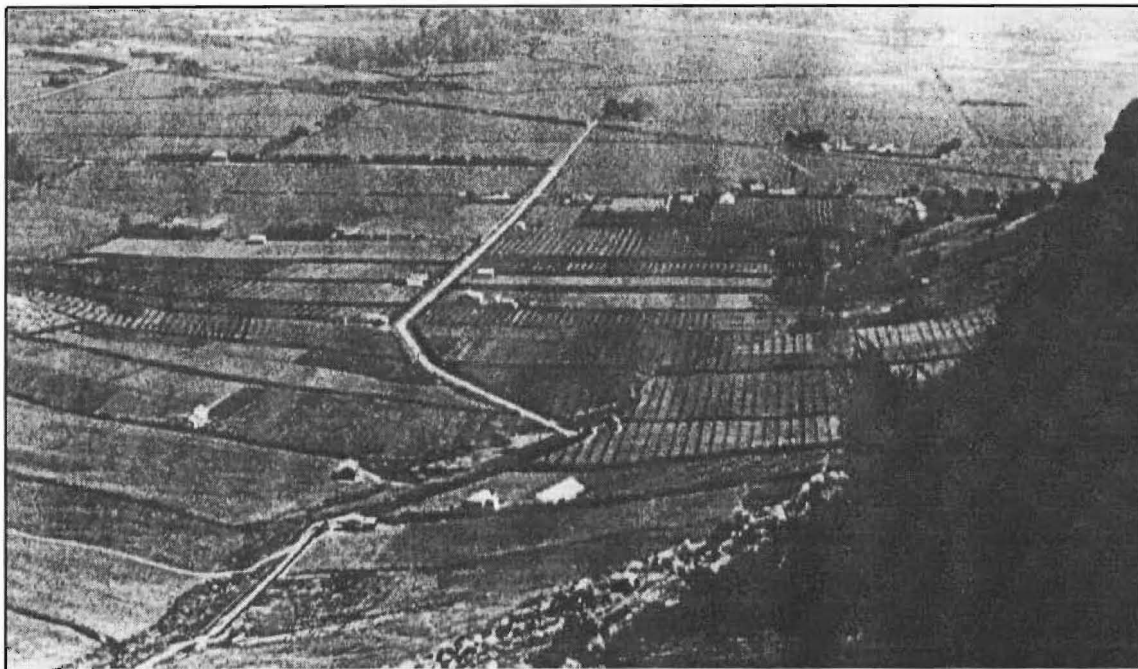


Plate 2.3 Land-use in the Horotane Valley 1919 - note the orcharding on the valley floor.

(Source: Ogilvie, 1978)

The early days were times of trial and error. Different crops were tried in different locations, with many successes and failures. Originally an extensive area of the valley was planted in apple trees, but like many other crops that were to follow, the growing conditions were not suitable. This was also the case with nectarines and peaches, which were susceptible to wet weather diseases. Apricots, plums and to a lesser extent cherries, have been the main fruits grown in the valley (Table 2.1). While there has been a decline in plums (8.2 to 4.9 ha) and cherries (1.4 to 0.6 ha) between 1948 (Kennelley, 1948) and 1973 (Dept of Ag and Fish, 1973), there has been increased specialisation in apricots (8.9 to 14.2 ha).

The valley climate is unique in Canterbury for its ability to produce suitable growing conditions for apricots. The growing season is thought to be comparatively longer in the valley because of the milder temperatures and fewer, if any, frosts. There has also been an increase in the number of glasshouse crops, especially tomatoes and flowers.

The amount of land under horticultural production has reduced over the years.

Land was subdivided prior to the 1958 Christchurch Regional Planning Scheme, under which all land in the Horotane Valley was zoned as rural and further subdivision was blocked. Land was also lost in the late 1950's with the building of the Lyttelton Tunnel and motorway. Smith and Mears (1975) investigated the impact of urban sprawl on the agricultural valleys of the Port Hills, including the Horotane. With the decrease in the average size of individual holdings (from 2.2 ha in 1948 to 1.2 ha in 1973), there has been intensification and specialisation in high income crops. Many of the residents who have not been able to adapt their land to this pattern of cropping, have found their small holdings are no longer viable units. Consequently, many have sold them as large residential units or to part time growers, hobby farmers and or land speculators. Smith and Mears (1975) surveyed growers in the area and reported that the majority of them saw subdivision for residential use as inevitable.

Table 2.1 Principal crops in the Horotane Valley 1948 and 1973

(Source: Smith and Mears, 1975)

Crop	1948	1973
Plums	8.2	4.9
Apricots	8.9	14.2
Cherries	1.4	0.6
Peaches	0.9	-
Small fruit	0.5	-
Spring cabbage	4.0	0.4
Lettuce	2.4	0.8
Celery	-	1.8
Tomatoes	12.5	-
Other vegetables and flowers	3.2	0.7
Glasshouse crops	-	3.6
Total area cultivated	42	27

At present the valley sides are the site of orcharding. There is also limited market gardening, especially of celery, spring cabbage and lettuce on the lower slopes and the valley floor. The valley floor is also the site of the many glasshouse tomatoes and flowers grown in the valley as well as the residential

houses. The upper half of the valley is used for extensive sheep and cattle grazing (Plate 2.4).



Plate 2.4 Current land-use in the valley - note the greenhouses on the valley floor, orcharding on the lower slopes and pastoral land on the higher slopes.

Another potential land-use in the valley is forestry. The physical limitation for most of the tree species is moisture availability. Growth rates for *Pinus radiata* on other areas of the Port Hills have proven favourable compared to the rest of Canterbury. However, on the dry, north facing slopes of the valley neither *Eucalyptus* nor *Macrocarpa* will grow well (Canterbury United Council, 1986). The other limitation for forestry that must be considered is visual amenity.

2.5 INSTRUMENTATION AND FIELD SITES

The microclimate of the Horotane Valley was monitored from the 14th February to the 30th June, 1995. Sensors were installed at a number of sites to measure the temperature and wind regime of the valley (Figure 2.6). Additional measurements of short-wave radiation and temperature were taken in a series of case studies to illustrate spatial and temporal variations.

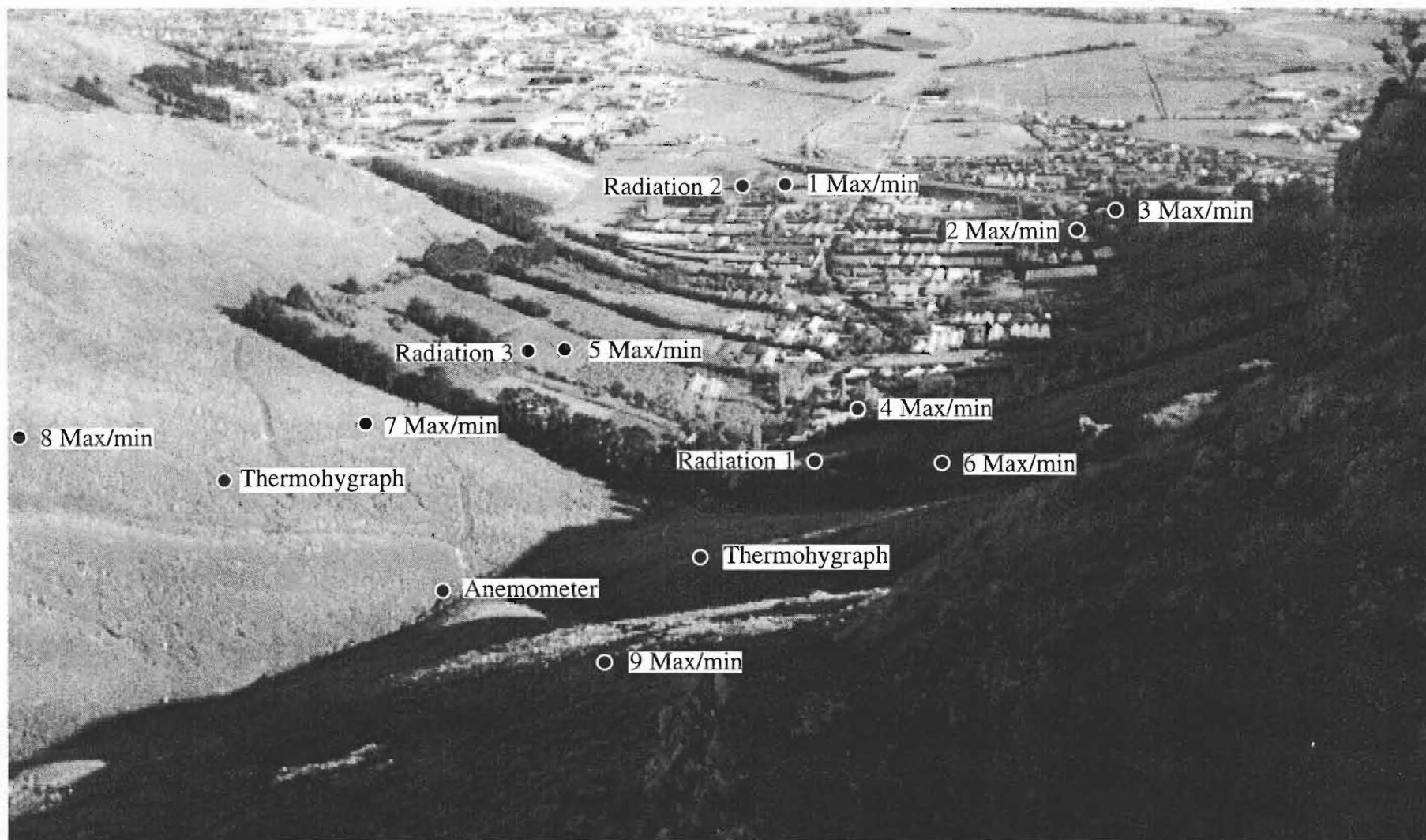


Figure 2.6 Location of field equipment (Max/min thermometers are numbered by relative height)

Maximum and minimum thermometers were used to gain an insight into the variability of the temperature regime in the valley. These thermometers were secured within a black radiation shield with holes drilled through it to allow ventilation, and placed inside an outer white shield (Plate 2.5). The shields are an inexpensive alternative to the Stevenson screen. Nine maximum and minimum thermometers were placed at strategic locations around the valley at heights of 1.2 m. The thermometers were located at sites with similar surface characteristics (grass, no shading etc) so that topography and altitude would be the main factors influencing the temperature. The thermometers were read and reset every morning between 0900 and 1030 hrs.



Plate 2.5 Maximum / minimum thermometer in radiation shield

A Lambrecht Anemograph was used to continuously record wind speed and direction at height of 2m. It was sited in the middle of the higher part of the valley to detect any katabatic and anabatic flows. It was intentionally sited away from buildings and trees, although a nearby *Macrocarpa* shelterbelt may have some influence.

Two thermohygrographs continuously measured the temperature and relative humidity. They were placed in Stevenson screens on top of a 2m high pole. Originally, one was located near the Summit Rd and the other was beside the anemometer. It was hoped to resolve the altitudinal differences, as the difference in altitude and exposure was quite large. The other thermohygrograph was sited in the middle of the valley, as it was thought this site would gain the most exposure to the sun. Unfortunately, the higher altitude thermohygrograph had to be removed on the 13th March, as it was subject to vandalism. Both thermohygrographs were then placed at the same elevation on different sides of the valley. This was to see if there were any differences in temperature and relative humidity between the different aspects. Charts were changed weekly, with the thermohygrograph reset to the correct temperature as given by the whirling psychrometer. Any differences were noted, so corrections could take place during analysis. A maximum / minimum thermometer was also kept in the Stevenson screen for the same purpose.

Field measurements were taken of incident and reflected solar radiation for the case studies. Sites were established on each side of the valley and on the valley floor. The measurements were not made simultaneously because of limited field equipment. Two Kipp and Zoen pyranometers measured the solar radiation from an extended arm at a height of 1 m. Air temperature at a height of 30 cm, and the soil temperature at 5 and 10 cm depths were also measured. The data was recorded on a Campbell CR21X datalogger.

2.6 SUMMARY

This chapter has established the physical setting of the Horotane Valley. The climate of the surrounding Canterbury Plains and some generalities of the

climate of the Port Hills were presented. The soils of the valley were outlined and the problems with erosion and water retention were identified. A land-use history of the valley was combined with present land-use to establish the crops that are successfully grown in the valley. Finally, the methodology used to collect the climate data was outlined. The following chapter investigates the characteristics of the short-wave radiation budget in the valley.

*Chapter Three***SHORT-WAVE RADIATION DISTRIBUTION IN
THE HOROTANE VALLEY**

3.1 INTRODUCTION

The spatially variable receipt of solar radiation at the Earth's surface is primarily responsible for the development of microclimates within areas of complex terrain. The first section discusses the radiation budget, with a focus on short-wave radiation as it is the most important flux for plant growth and primary heating of the air and soil.

3.2 THE RADIATION BUDGET

The radiation budget represents the amount of energy available for exchange within the boundary layer. Imbalances in the radiation budget lead to differential heating of the Earth's surface. The budget partitions radiation on the basis of wavelength and direction. Net all-wave radiation can be expressed as:

$$Q^* = K\downarrow - K\uparrow + L\downarrow - L\uparrow \quad (\text{Eq. 3.1})$$

where Q^* = net all-wave radiation

$K\downarrow$ = incoming short-wave radiation

$K\uparrow$ = reflected short-wave radiation

$L\downarrow$ = incoming long-wave radiation

$L\uparrow$ = outgoing long-wave radiation.

3.3 THE SHORT-WAVE RADIATION BUDGET

3.3.1 Incoming short-wave radiation

Short-wave or solar radiation is energy emitted by the sun, with wavelengths that range from $0.15\mu\text{m}$ (ultra-violet) to about $3.0\mu\text{m}$ (infra-red). Short-wave radiation is important as about (47%) of this incident energy is absorbed at the Earth's surface, with subsequent warming (Oke, 1987). It is also important for activating metabolic activities within plants, as discussed in section 1.3.1.

Short-wave radiation $K\downarrow$, is received at the surface as diffuse (D) or direct beam (s) radiation:

$$K\downarrow = D + S. \quad (\text{Eq. 3.2})$$

Diffuse radiation arrives at the surface after being scattered and reflected by atmospheric constituents such as water vapour, particulates and gases. On a cloudy day the proportion of incoming diffuse radiation increases. In the absence of cloud, diffuse radiation represents about 10-25% of the incoming short-wave radiation. It can arrive at the surface from any direction in the atmosphere and hence, it does not vary much spatially. The amount of diffuse radiation received at the surface is not controlled by aspect and slope to the same extent as direct radiation.

The amount of direct beam short-wave radiation received at the surface depends greatly on the orientation of the surface. Direct beam radiation reaches the surface as a parallel beam, after avoiding absorption and scattering in the atmosphere. The amount of short-wave radiation received or the irradiance of a surface, can be calculated for any time of the day of the year by referring to the "Cosine Law of Illumination":

$$S = S_i \cos \Theta \quad (\text{Eq. 3.3})$$

where S = flux density of beam radiation at surface

S_i = flux density normal to the beam

Θ = angle between the beam and the normal to the surface.

A simple relationship can be drawn between the orientation of the surface and the resulting irradiance. The amount of radiation arriving at the surface remains constant but when the surface is inclined, the incoming beam covers a larger area and therefore the irradiance is decreased (Figure 3.1). The dependence of radiant intensity on slope angle and aspect for a southern hemisphere site is illustrated in Figure 3.2.

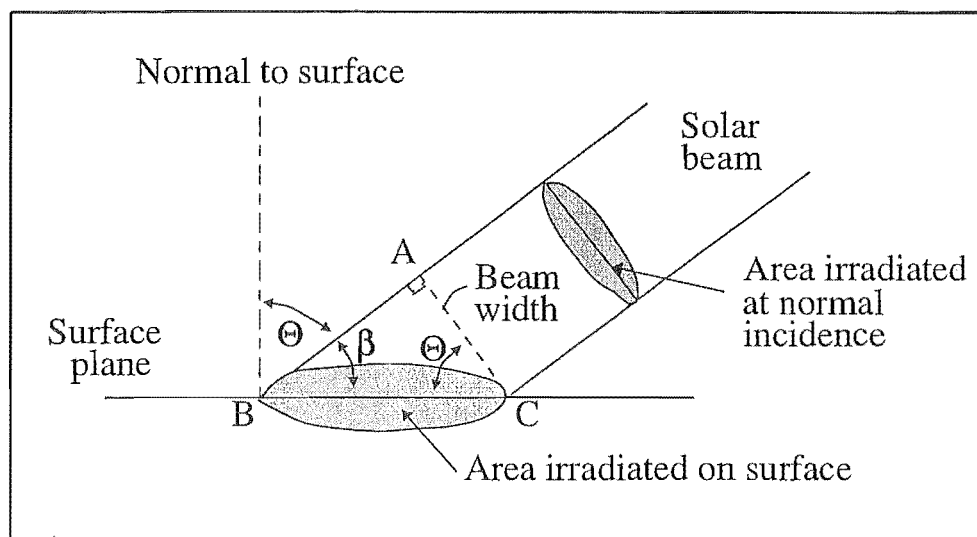


Figure 3.1 Reduced irradiance over a surface at an angle to the beam

(Source: Oke, 1987)

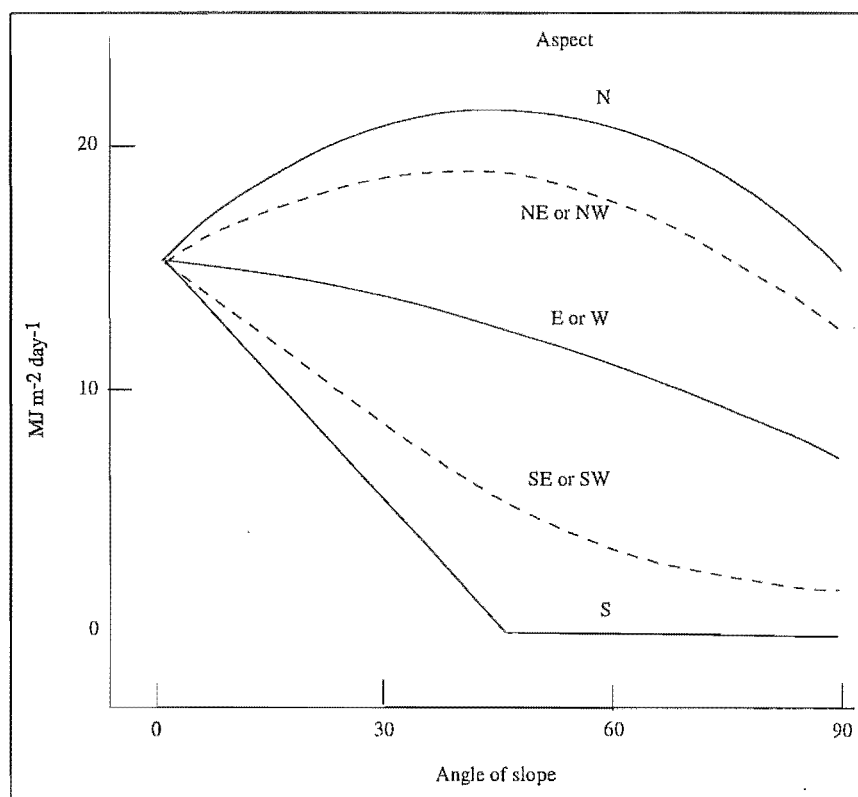


Figure 3.2 Variation in radiation receipt with aspect for the Southern Hemisphere

(Source: Oke, 1987)

3.3.2 Reflected Short-Wave Radiation

A portion of the incoming short-wave radiation is reflected back to space. The amount reflected is influenced by the quantity of incoming short-wave radiation and is also dependent on the nature of the receiving surface. The portion of incoming short-wave radiation that is not reflected is absorbed or transmitted by the surface.

3.3.3 Albedo

The short-wave reflectivity of the Earth's surface is referred to as the albedo (α). This is the ratio of reflected short-wave radiation to the total incoming short-wave radiation and it is influenced by the nature of the surface including the colour, roughness and moisture content. Table 3.1 indicates the albedos of a range of natural and built surfaces. Albedo values are important in microclimate studies, as surfaces with lower values can absorb more incoming radiation and therefore increase the amount of energy that is available for heating the ground and air, and for potential evaporation.

Table 3.1 Typical albedo values for a range of surfaces

(Source: Ayra, 1988)

Surface type	Other specifications	Albedo
Water	Small zenith angle	0.03-0.10
	Large zenith angle	0.10-0.50
Bare soil	Dry clay	0.20-0.35
	Moist clay	0.10-0.20
	Wet fallow field	0.05-0.07
Paved	Concrete	0.17-0.27
Grass	Long (1m)	0.16-0.26
	Short (0.02m)	
Agricultural	Wheat, rice, etc.	0.10-0.25
	Orchards	0.15-0.20
Forests	Deciduous	0.10-0.20
	Coniferous	0.05-0.15

3.4 CASE STUDIES OF THE SHORT-WAVE RADIATION BUDGET IN THE HOROTANE VALLEY

Short-wave radiation measurements were made at three sites within the valley to illustrate the spatial and temporal variations. Clear skies were required for the majority of the day so the field measurements took place over a ten day period when the weather was suitable. Location of the sites is illustrated in Figure 2.6.

On 11 July, 1995 measurements were taken on a 30° north-west facing slope at an elevation of 90 m. The site was predominantly grass with a low density planting of small apricot trees to one side. Clear skies prevailed for most of the day, with just a few small cumulus clouds obscuring the sun around noon. Measurements on the east facing slope were taken on the grassy pasture above an orchard, at a height of 120 m. Low cloud covered the sky for most of the morning (21 July, 1995), but once this lifted the sun remained unobstructed for the majority of the afternoon. Measurements were taken on the valley floor on 28 July, 1995. The sky was clear for the majority of the day. Computer modelling of the incoming radiation using the "Cosine Law of Illumination" (Eq. 3.3) was undertaken for the same dates.

3.4.1 Incoming radiation distribution in the Horotane Valley

There is large spatial and temporal variation in radiation receipt in the valley caused by the varying aspects and slope angles (Figure 3.3). The east facing slopes of the valley receive the sun earliest in the day (0800 hrs and 0801 hrs for the valley and the Airport respectively) but lose the direct sun early on in the afternoon (1515 hrs compared to 1709 hrs at the Airport). The total amount of short-wave radiation received at this site during the day was 5.98 MJ/m². This compares with the model output of 7.50 MJ/m² for a 30° east facing slope. The lower amount is probably due to the low cloud cover reducing incoming radiation in the morning and the reduced sky view factor when compared to the model.

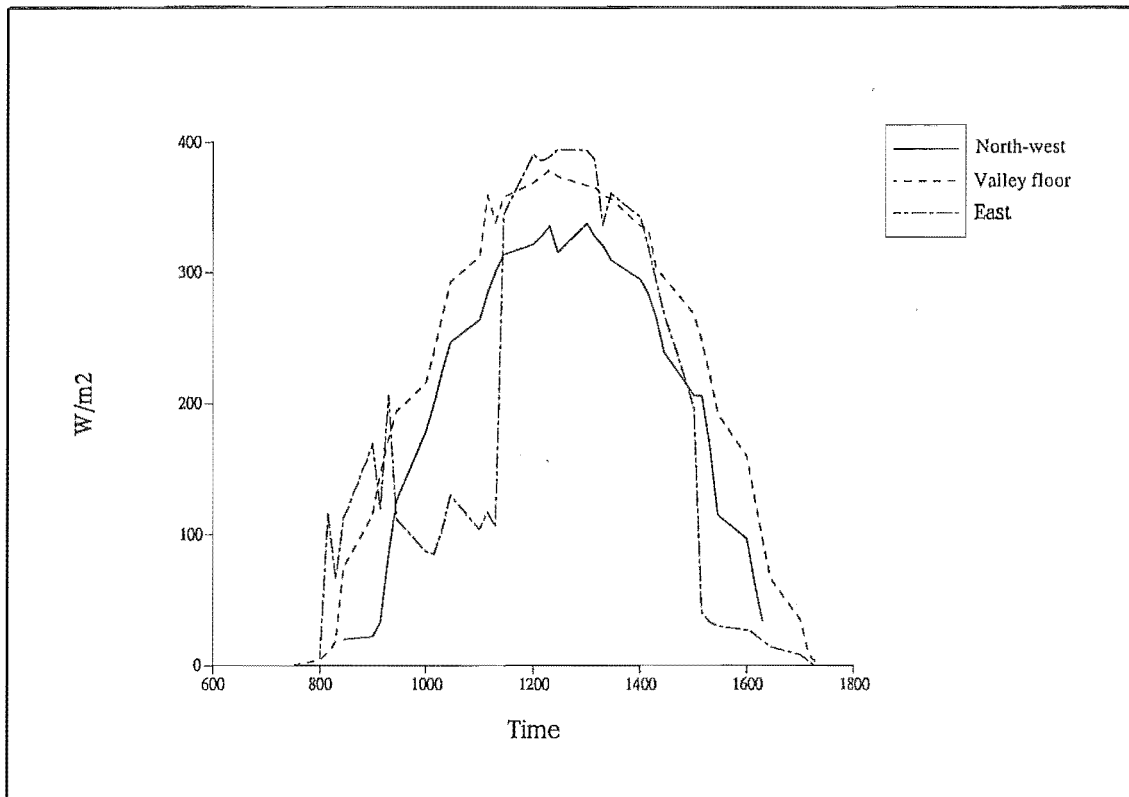


Figure 3.3 Short-wave radiation receipt in the Horotane Valley

While the north-west facing slopes were not exposed to direct sunlight until later in the morning (0930 hrs compared to 0754 hrs at the Airport), they were compensated by having sun for longer in the afternoon (1615 hrs and 1717 hrs respectively). The length of time that the west-facing slopes remain in shade is extended by the positioning of shelterbelts along the ridgeline. Shadows are cast that do not exist on adjacent properties. Plate 3.1 illustrates the early morning shading of the north-west facing slopes. The total amount of incoming radiation (6.18 MJ/m^2) was much less than that proposed by the model (13.40 MJ/m^2 for a 30° north-west facing slope). This can probably be attributed to the earlier afternoon shading of the site by the east facing slope and the clouds present around noon.

The lower part of the valley floor has the longest daylength (0745 hrs to 1730 hrs). The valley sides surrounding this area are lower than the upper part of the valley. Hence, the sun is able to penetrate the valley earlier and it is not obscured by the slopes in the afternoon. The day-length on the valley floor is identical to that of the Christchurch Airport (0748 hrs to 1724 hrs). Differences between the total short-wave radiation receipt on the valley floor (7.88 MJ/m^2)

and the ideal value produced by modelling (8.50 MJ/m^2) can be explained by the reduction caused by cloud cover and possible filtering by air pollution.



Plate 3.1 Shading of the north-west slope - 9am, 20th October, 1995.

The intensity of radiation received at the surface also varied amongst the selected locations. The east facing slope received the highest amount of incoming radiation averaged over a 15 minute period (394 W/m^2 at 1300 hrs). This high value may be attributable to the intermittent cloud cover during the morning. Monteith and Unsworth (1990) note that under such conditions, irradiance reaches a peak for a few minutes before and after the sun is obscured by cloud. This is a result of strong forward scattering by the small concentration of water droplets present at the edge of a cloud. The valley floor received marginally less (379 W/m^2 at 1230 hrs), with the north-west facing slope receiving the lowest amount (338 W/m^2 at 1300 hrs).

According to the radiation modelling, slopes of greater angle should receive higher quantities of radiation in winter as demonstrated above, with the opposite true in summer. Calculations of short-wave radiation input for the valley on the 1st January give daily totals of 30.90 MJ/m^2 for a horizontal surface, 29.20 MJ/m^2 for a 30° north-west facing slope and 28.30 MJ/m^2 for a 30° eastern slope.

3.4.2 Albedo variation within the Horotane Valley

The surface characteristics at each site were quite varied, although each had grass as the principle cover. The north-west slope had short, wet grass (5-10 cm long); the valley floor also had short, wet grass (5-10 cm) but with patches of mud; and the east slope had longer grassy vegetation about 30 cm high. Although the measurements were taken on different days, the values are comparable because they represent a ratio of incoming and reflected radiation that depends on the surface characteristics, rather than the short-wave input on the day. Figure 3.4 illustrates the relationship between incoming and reflected radiation on the valley floor.

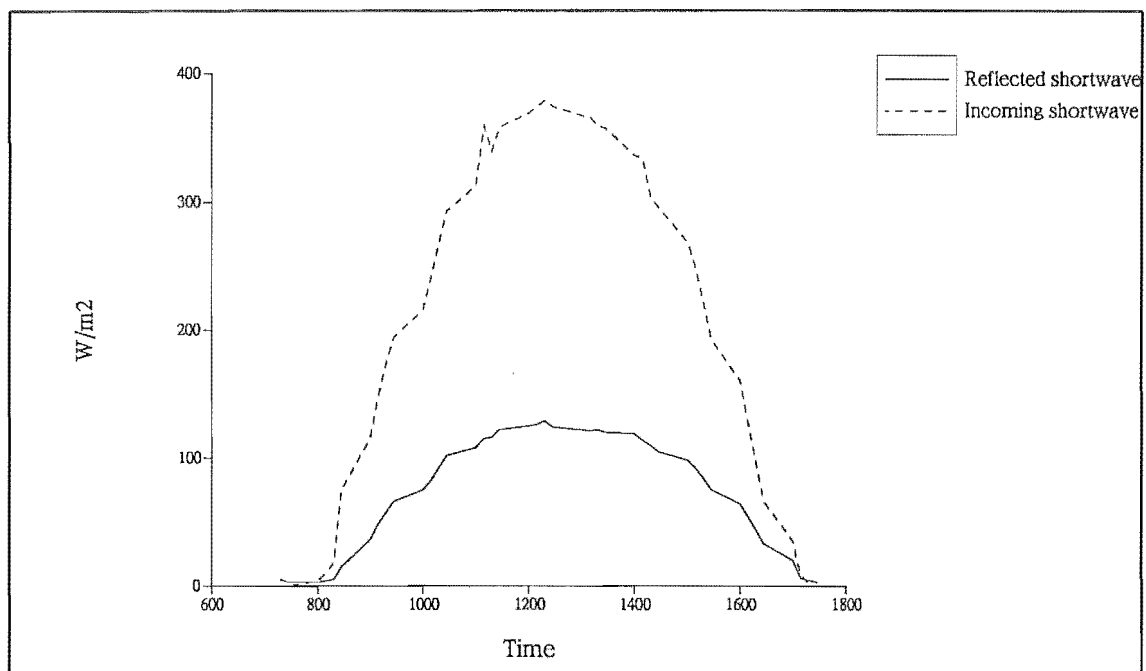


Figure 3.4 Relationship between incoming and reflected radiation on the Horotane Valley floor, 28 July 1995.

The albedos of the valley floor and the eastern slope followed a similar pattern through the day, with high values in the morning and following sunset (Figure 3.5). This represents the time when the amount of incoming and reflected radiation are both minimal, and therefore the ratio of each is more equal. During the day the albedo drops as the amount of incoming radiation far exceeds that which can be reflected.

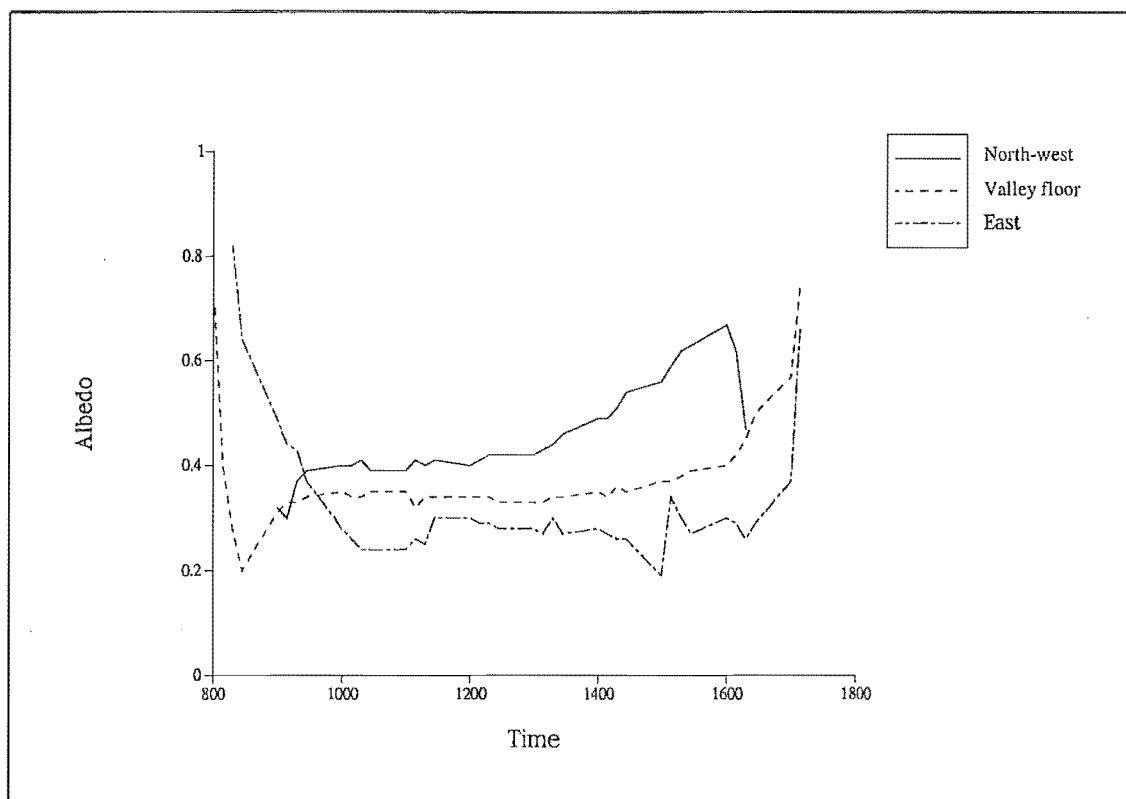


Figure 3.5 Diurnal variation in albedo in the Horotane Valley

The average albedo between 1100 to 1300 hrs was calculated for each site. The north-west slope recorded the highest average albedo (0.41). This is greater than usual values for grass (0.16 to 0.26) and may be attributable to the wetness of the grass. The albedo values for a water surface range from 0.10 to 0.50 for a large zenith angle. With the measurements taken in winter, the zenith angle of the sun is at its greatest and the albedos can be expected to be correspondingly high. The average albedo for the valley floor was calculated to be 0.34. This is still high considering the equipment was measuring reflected radiation from patches of wet soil (0.05 to 0.07 for a wet fallow field). The east facing slope had the lowest average albedo (0.28) that still represents a high value for grass. The comparatively lower albedo at this site may be due to the length of the grass and the fact that the grass was not as wet as the other sites.

Maximum values are more likely to occur over surfaces that are more uniform, such as short grass compared to 30 cm long grass. This is because less radiation is trapped by the multiple reflection of radiation between adjacent leaves and stems (Monteith and Unsworth, 1990). This would further explain the higher values on the north-west facing slope as this site had the most uniform surface,

with shorter grass than the east facing slope.

3.4.3 Temperature and incoming radiation

The relationship between the amount of incoming short-wave radiation and the corresponding air and soil temperatures on the eastern slope is illustrated in Figure 3.6. Air temperature is responsive to rises and falls in incoming radiation, although there appears to be a lag time of an hour from when radiation levels first reach their peak until air temperature does.

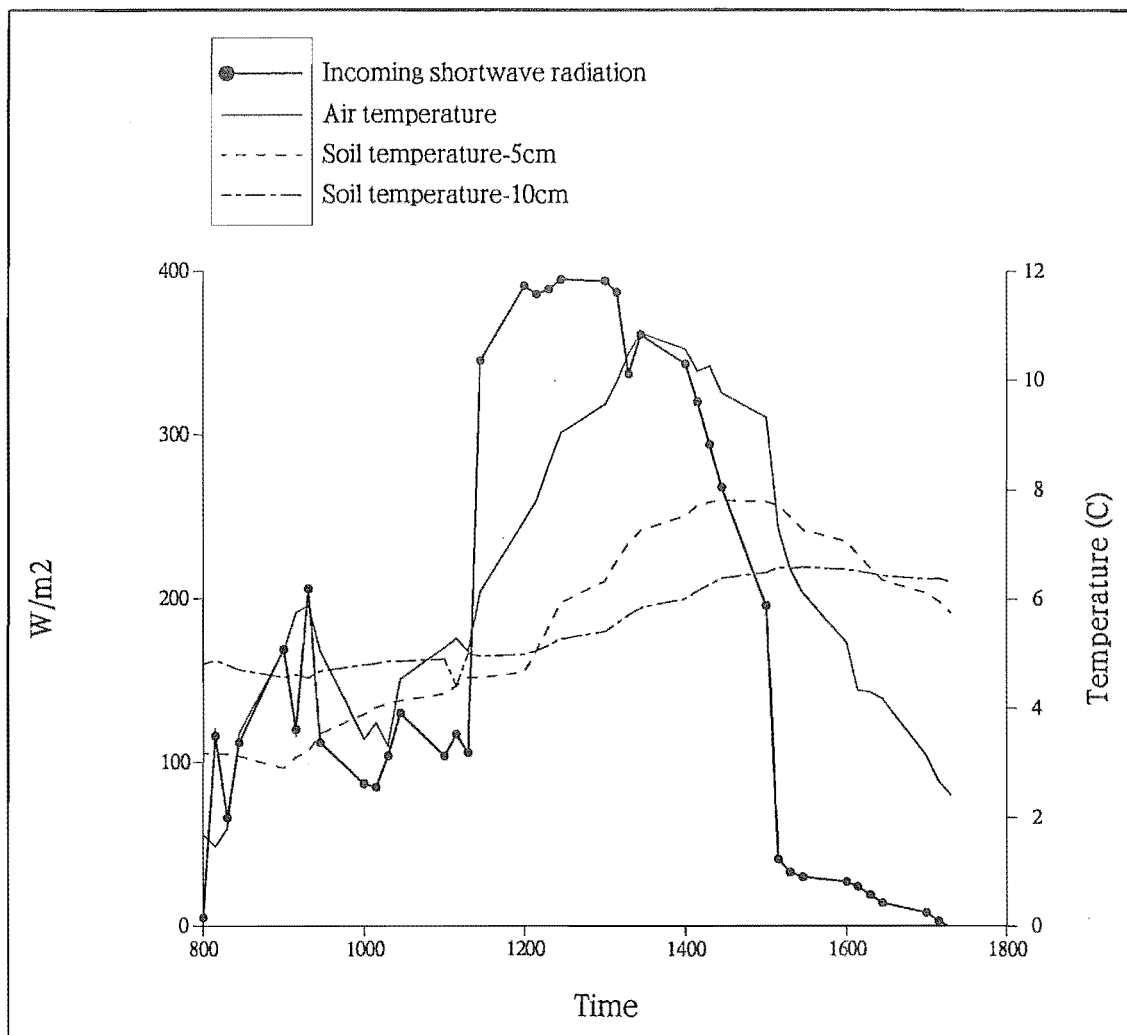


Figure 3.6 Incoming radiation and air and soil temperature relationships for the east facing slope, 21 July, 1995

Soil temperatures remain more constant. At the beginning of the day soil temperatures are cooler closer to the surface. This is the result of nocturnal radiative cooling at the surface. During the day the incoming radiation absorbed at the surface heats the soil from the top down. For this reason the soil becomes warmer closer to the surface, and at its peak it is only 3°C cooler than the maximum air temperature. The soil at 10 cm takes longer to warm up but it continues to warm once radiation levels drop.

3.5 SUMMARY

An attempt to establish the spatial and temporal variation in radiation receipt produced a general overview of the differences caused by topography and surface characteristics. The case studies gave a first approximation of the differences in short-wave radiation receipt in the valley during winter. Further measurements taken over a number of varying surfaces and at different times of the year are necessary to establish the short-wave radiation budget of the valley. The variation in radiation receipt in the valley is due to the varying aspects and slope angles presented by the topography. Daylength varied according to aspect and elevation, with the longest being recorded on the valley floor and the shortest on the north-west slope. The deviations in the predicted solar radiation totals from the observed totals of the east and north-west facing slopes are probably due to the reduced sky view factor and cloud cover.

Albedo is more dependent on the nature of surface than the slope angle or aspect and the more uniform the surface, the more radiation is reflected and hence the higher the albedo. The albedos measured were all higher than expected. The north-west slope recorded the highest albedo (0.41), while the valley floor (0.34) and the east facing slope (0.28) recorded comparatively lower values. The high values at all sites is probably due to the wetness of the surface and the high zenith angle of the sun. The difference between the sites may be due to the variation in the length of grass and the uniformity and wetness of the surface.

The effect of radiation on air and soil temperature was also investigated. Air temperature was responsive to increases and decreases of radiation input, however, there was a lag time of an hour between peak values. The soil was

more responsive to variations in radiation intensity closer to the surface. The distribution of temperature within the valley can be considered to be partially due to imbalances in the short-wave radiation budget with topographic variation. The following chapter investigates the resultant temperature regime within the Horotane Valley.

Chapter Four
**THERMAL REGIME OF THE
 HOROTANE VALLEY**

4.1 INTRODUCTION

The Horotane Valley has a reputation for having warmer temperatures than the surrounding Canterbury Plains. The following chapter investigates the temperature regime of the valley, and in particular, the temperature distribution as an expression of horticultural growing potential. The first section details the distribution of growing degree days in the valley, while the second section discusses winter chilling. Finally, the distribution of minimum temperature and frost incidence in the valley is discussed.

4.2 GROWING DEGREE DAY DISTRIBUTION

Growing degree days (GDD) were calculated for each site for the period October to April at a base temperature of 10°C. Although the Meteorological Service (1978) and Turner and Fitzharris (1987) used November to April as the growing season, a number of publications that specify GDD crop requirements have used the longer period (e.g. Kerr *et al.*, 1981). Similarly, a base temperature of 10°C is commonly used throughout the literature for calculating GDDs. GDDs were calculated using the following equation:

$$d = n$$

$$D = \sum (T - B)$$

$$d = 1$$

where D = number of degree days over a period

T = mean temperature for each day (d), calculated as the average of
 daily maximum (T_{max}) and minimum (T_{min}) values (°C)

B = a predetermined base temperature crop ($^{\circ}\text{C}$), which can vary with the crop

n = number of days in the warm season.

Fieldwork was restricted to the period from 14th February to 30th June so to expand this data set valley temperatures were compared with temperatures at Christchurch Airport. Correlation analysis showed a strong relationship between the mean temperature at each site and the Airport (Appendix 2a). By using linear regression analysis, temperatures were predicted for Site 1 ($r^2 = 0.82$) and extrapolated to cover the October to February period when no data was available from the valley. Figure 4.1 illustrates the relationship between the Airport and Site 1 mean temperatures. Prediction of Site 1 values is given by the straight line, while the dotted lines represent the estimated 95% confidence interval for the predicted data.

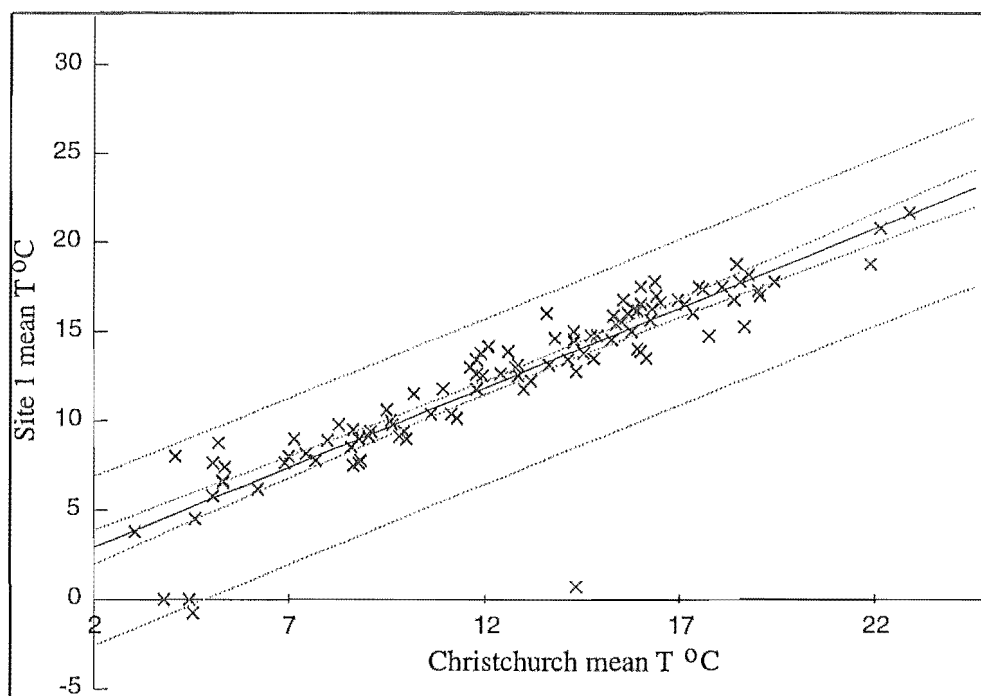


Figure 4.1 Predicted mean temperatures for Site 1 with estimated 95% confidence intervals for the regression line

The variation in GDDs throughout the valley is clearly illustrated in Figure 4.2. The values range from 963 to a high of 1201. This difference can determine the success or failure of certain crops (see Chapter 7). The lowest accumulation of growing degree days is found on the valley floor. This is reflective of the lower minimum temperatures experienced at this location due to the development of

temperature inversions. The lower valley walls have significantly higher amounts of GDD than the valley floor. This can be attributed to the moderating effect of higher minimum temperatures. GDDs increase with elevation and reach a maximum at around 50-60 m. At this height there are fewer frosts and night temperatures are generally higher. Above this height GDDs decrease steadily. The depressing effect of the lower maximum temperatures on the mean, counteract the greater minimum temperatures experienced at the higher elevations. With the exception of the valley floor, the whole of the valley (>10-20 m) has higher GDD accumulations than the Christchurch Airport (1018).

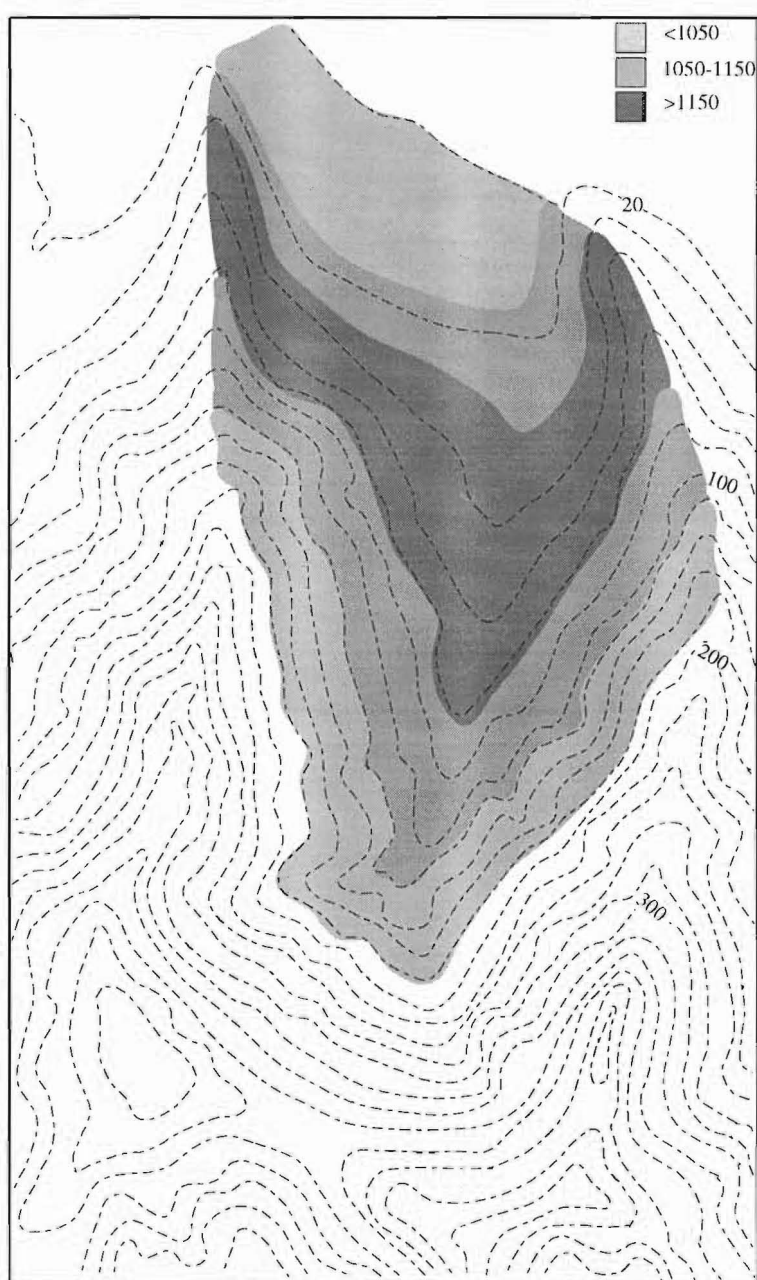


Figure 4.2 Growing degree day distribution in the Horotane Valley

4.3 CHILL UNIT DISTRIBUTION

Chill units were calculated for each site for a five month period, from the average date of the first screen frost (7th May) until the end of September. The first air frost is commonly used in New Zealand as an indicator of the onset of the rest phase of plants (e.g Kerr *et al.*, 1981). As with GDDs, the data collected during the restricted field period was extended by linear regression analysis with the Christchurch Airport data (Figure 4.3).

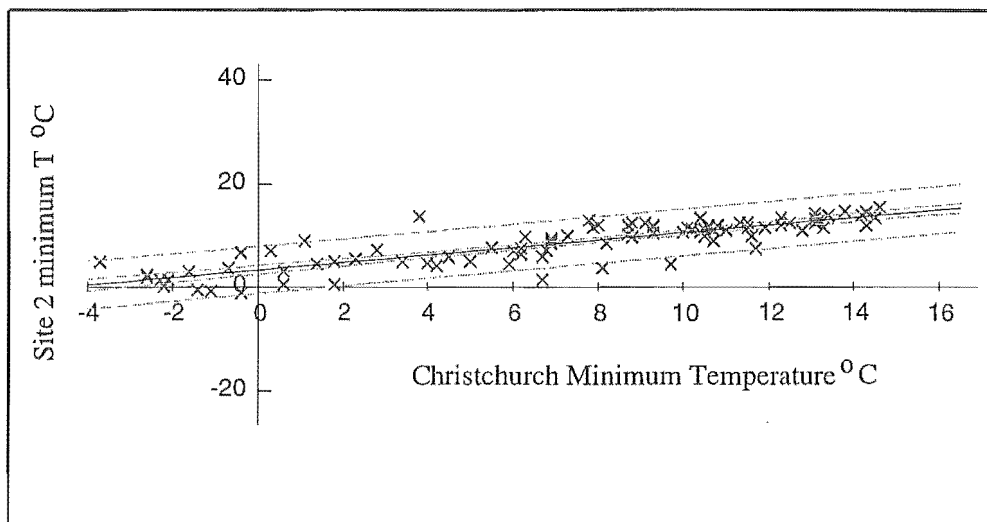


Figure 4.3 Predicted minimum temperature at Site 2 with 95% confidence interval for the regression line

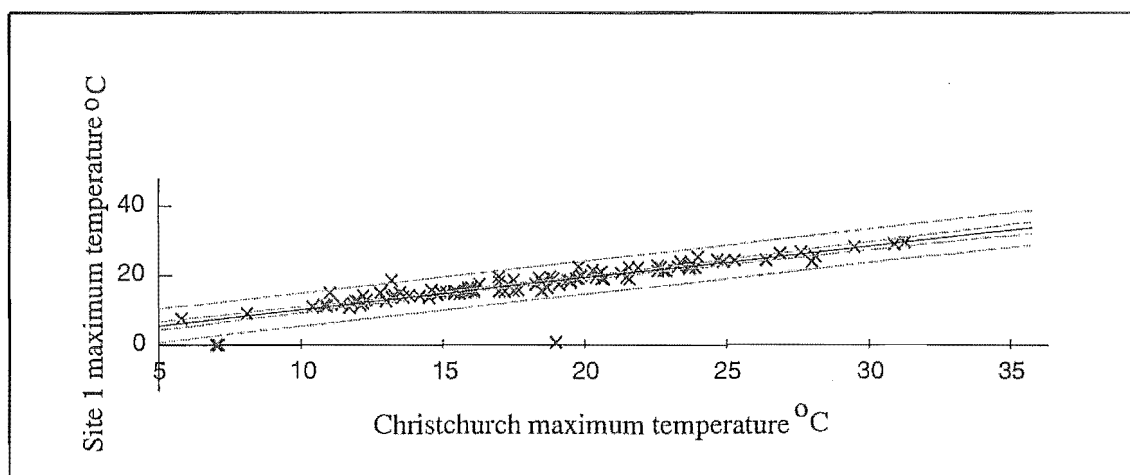


Figure 4.4 Predicted maximum temperature at Site 1 with 95% confidence interval for the regression line

Site 2 exhibited the strongest relationship with the Airport minimum temperatures ($r^2 = 0.72$). The data for this site were calculated from the Airport data, and subsequently used to predict the missing data at the other sites. The maximum temperature data showed a high correlation between all sites and the Airport (Appendix 2c). Regression analysis between the Airport and Site 1 yielded an r^2 value of 0.81 (Figure 4.4). Following extension of the database, the chill units were calculated from a spreadsheet by assigning the values given in Table 1.1 (p. 8).

The highest accumulation of chill units occurred on the valley floor (Figure 4.5).

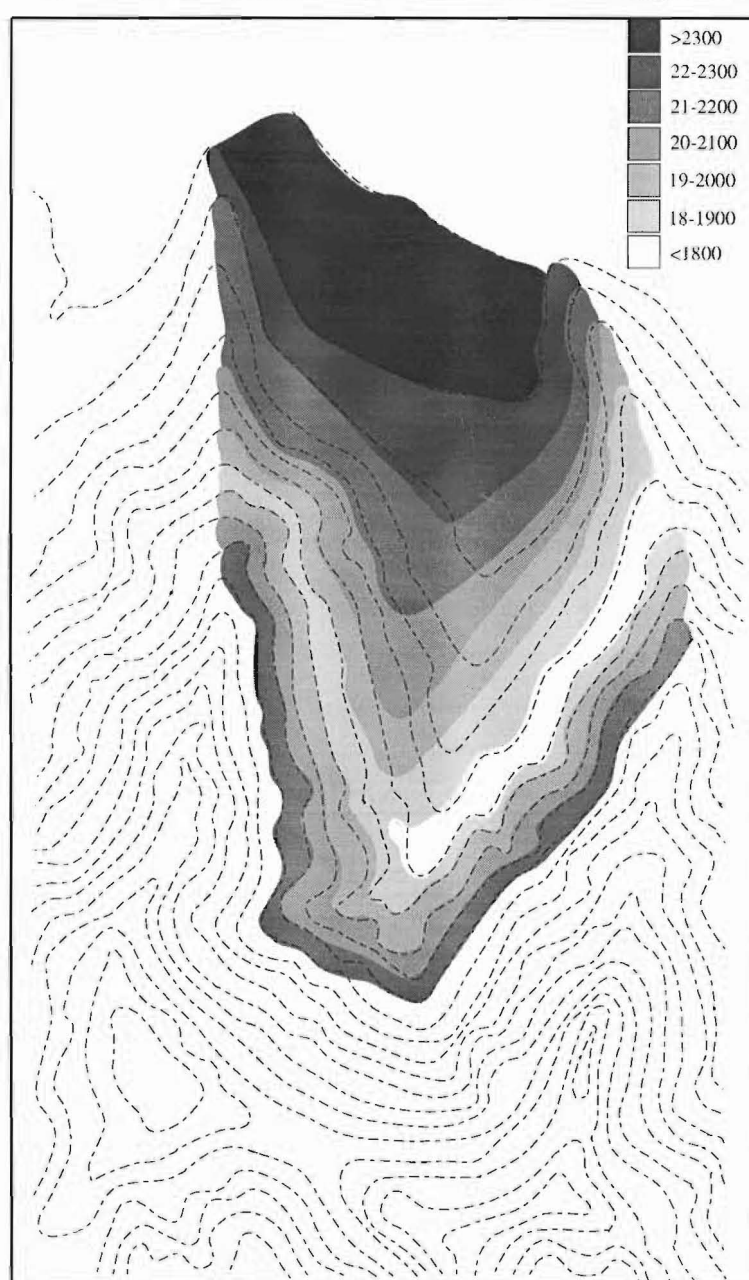


Figure 4.5 Chill unit distribution in the Horotane Valley

Explanation of the chill unit regime in the valley is not as straight forward as the GDD, which can be assessed directly from mean maximum and minimum temperatures. Although more susceptible to frost and, therefore, administered with zero value chill units, the lower temperatures experienced on the valley floor during temperature inversions (e.g. 5°C compared with 8°C at the higher locations) give more time for chill unit accumulation. With hourly temperatures predicted by a linear model, the lower the minimum temperature is, the more hours that are spent at the lower temperatures, and therefore the more likely the site is to accumulate a higher chill unit value (Figure 4.6).

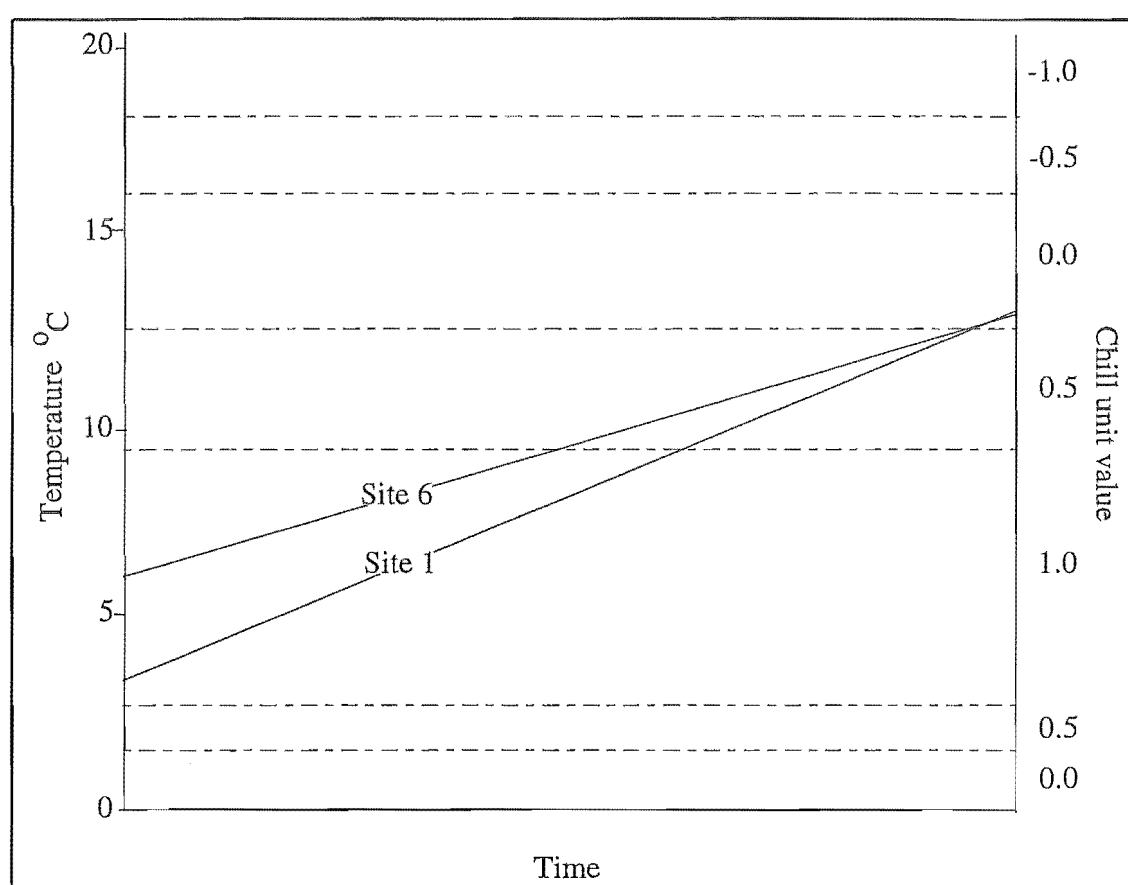


Figure 4.6 Designation of chill units for Site 1 and 6

Christchurch Airport, which had consistently lower mean monthly maximums and minimums than the valley floor, accumulated a lower chill unit value (2091) than the valley floor (2361). At first glance this appears to contradict the above assumption. Following examination of the individual data it is apparent that at the Airport more time is spent at temperatures that are assigned zero chill units because of the lower maximums.

Chill unit totals decreased with elevation to a height of approximately 100 m on the eastern slopes and 125 m on the western slopes. The higher mean maximum and minimum temperatures up to this elevation result in more time spent in the lower accumulation phases. Above this elevation chill units begin to accumulate once again, although accumulation is a result of lower maximum temperatures, not lower minimum temperatures as experienced on the valley floor.

Aspect appears to play an important role in chill unit distribution. On the eastern side of the valley the chill units were lower than for the equivalent elevation on the western slopes. This can be attributed to the overall higher maximum temperatures experienced on the eastern slopes because of radiation loading.

4.4 MINIMUM TEMPERATURE DISTRIBUTION

Growing Degree Days and Chill Units are a reflection of the temperature distribution within the valley. Minimum temperatures within the valley exhibit greater variation than do the maximum temperatures. They are also of significance because of the implications for frost. Maximum temperatures tend to decrease only slightly with elevation.

4.4.1 Temperature inversion

It is usual to expect an adiabatic decrease in temperature of 0.6°C for every 100 m into a well-mixed atmosphere. However, in some instances and more importantly, at the local scale, minimum temperatures can be seen to increase with height. This is known as a temperature inversion (Figure 4.7).

The degree to which temperature increases with elevation is dependent on a number of controls. These include the synoptic situation for the air mass origin and the stability of the atmosphere. For example, a strong southerly gradient flow over the South Island, will create a well mixed atmosphere with uniformly low minimum temperatures. In contrast, when there is an anticyclone situated

over the country, the air is calm and conditions are conducive to radiative cooling and katabatic drainage. Under these conditions minimum temperature stratification is more likely to occur.

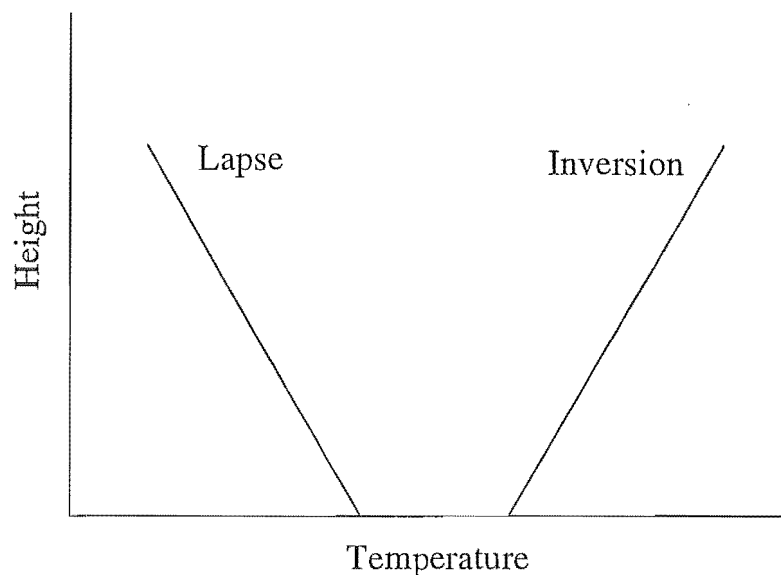


Figure 4.7 Idealised temperature profiles (After: Oke, 1987)

Temperature inversions are most commonly thought of as occurring in winter, when radiative cooling leads to frost development. Although this is the most visually obvious time, the same processes that lead to inversion development in winter are also responsible for temperature inversions in the valley during the summer months. Conditions leading to the development of either an inversion or the normal lapse rate are presented by means of two case studies in the Chapter 6.

A "thermal belt" is said to exist at the top of the inversion layer, before the temperature gradient returns to the normal lapse rate (Oke, 1987). This belt has the highest temperature during an inversion and therefore the smallest frost risk and hence, is ideal for frost sensitive crops. The top of the inversion layer was not identified by the thermometer network during the study period. The network encompassed all of the valley presently under horticultural use and reached a height that would be unviable for horticultural activity due to steepness and soil depth. Additionally, after examination of the data, it appears the thermal belt would not remain static, but would instead vary with changing synoptic conditions.

4.4.2 Normal lapse rate

Analysis of the field results showed that the "normal" lapse rate was attained on only 35 of the 121 days in the study period. As Laughlin and Kalma (1988) noted, the lapse rate becomes normal when the atmosphere is well mixed. This was confirmed by the field results, which found the reversal of lapse rate to occur when there was a strong gradient wind through the night. These events were commonly found to be accompanied by cloud cover and precipitation. This association was also noted by McGowan (1990) in his microclimatic study of Waimate. During these conditions, an inversion is unable to develop or is destroyed because the surface cooling is counteracted by warmer air being mixed in from above.

4.4.3 Frost occurrence

Frosts are common in the lower reaches of the valley during the winter months. The limitations on frost development caused by differences in elevation are visually obvious in the valley, as during only 40% of the recorded frost events, were air frosts recorded at sites other than site 1 (on the valley floor). On these occasions site 1 recorded severe air frosts of -1.5 to -3.5°C. The altitudinal limits for frost development depend on the larger scale synoptic situation. The severity of the frost at site 1 and the extent to which the frost line is able to penetrate up the valley appears to be closely related. Figure 4.8 presents a general frost risk map for the valley compiled from the available data and field observations. Classification from high to low is based on the chance of frost occurrence when Christchurch experiences frost.

Frosts were found to occur to a height of 60 to 80 m, depending on the siting of shelterbelts, buildings etc. Frosts that occurred directly upslope of the large *Macrocarpa* shelterbelt were not uncommon and obviously the result of cold air ponding. There were occasions during the research period when frost was recorded on the valley floor but not in Christchurch. This is attributable to the occasions when a westerly or easterly inhibits frost development at the Airport but being topographically sheltered, frost is able to develop in the valley.

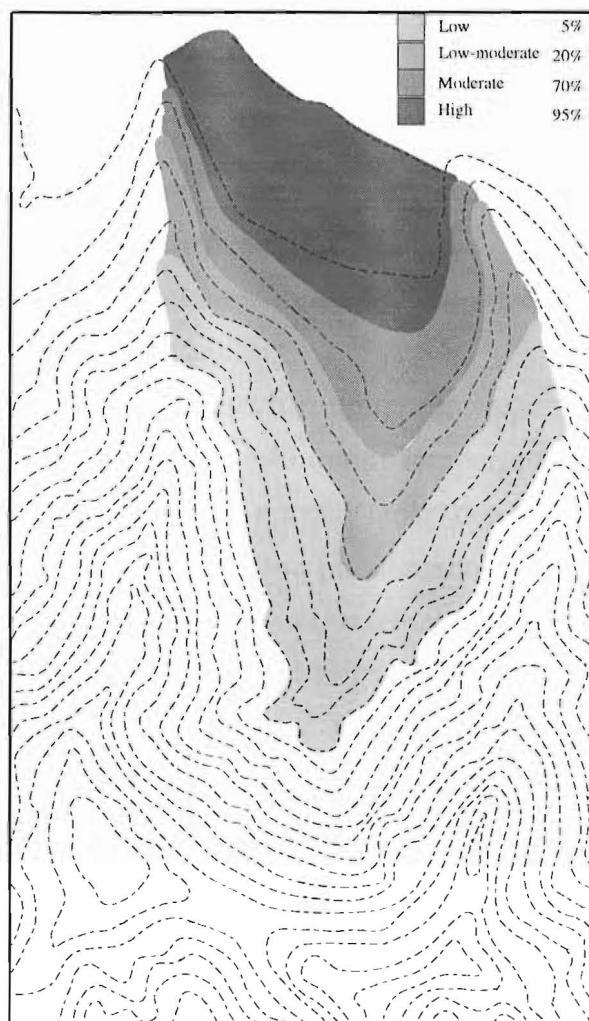


Figure 4.8 Frost risk in the Horotane Valley

4.5 SUMMARY

Growing degree days increased with elevation from 963 on the valley floor to a maximum of 1201 at a height of 50 to 60 m. The increase was a direct result of the higher minimum temperatures experienced with elevation in the valley during temperature inversions and associated frost events. Above this height the lower maximum temperatures counteracted the higher minimum temperatures to decrease the GDDs. Beyond the study area, the GDDs are expected to continue to decrease with elevation. GDDs above 10 to 20 m in the valley were also considerably higher than at the Christchurch Airport (1018).

The effects of maximum and minimum temperatures on chill unit distribution are not so clear. Temperatures are assigned the maximum value between 2.5 to 9.4°C. Above and below this, the accumulation values decrease and even

9.4°C. Above and below this, the accumulation values decrease and even become negative above 16°C. Therefore, high chill unit totals can be an expression of both low maximum and minimum temperatures, or high minimum and low maximum temperatures. Chill unit totals graded from a maximum on the valley floor to a minimum between 100 m on the eastern slope and 125 m on the west slope. Beyond this, accumulations began to rise again.

From the calculations of GDD and chill units, the importance of the minimum temperature distribution emerges. Minimum temperatures in the valley either follow an inversion pattern or the normal lapse rate. Due to the temperature inversion, frost occurrence is a common phenomenon on the valley floor. Frost incidence decreases with elevation as warmer minimum temperatures are encountered. There are increased frost risks associated with obstacles such as shelterbelts and buildings, as the cool katabatic wind may become ponded behind them, increasing the usual frost risk. The following chapter investigates the development of katabatic and other thermotopographically generated winds in the valley.

*Chapter Five***WIND REGIME OF THE HOROTANE VALLEY**

5.1 INTRODUCTION

This chapter firstly presents the theory on the development of various winds that may be present in valley systems. The remainder of the chapter investigates the wind regime of the Horotane Valley. A comparison is made with the wind regime of the Bromley and Christchurch Airport sites. This will enable identification of any locally generated thermotopographic winds within the valley. Due to the seasonally variable wind climate of Canterbury, the study period was divided into summer (February to April) and winter months (May to July). Wind roses were the primary tool for analysis of the spatial and temporal variation in wind patterns. Each arm of the wind rose represents the frequency of wind from the direction it is pointing and the width of the line represents the wind strength. Intercomparisons of wind at the sites are made with caution as they were recorded with different instruments and at different elevations.

5.2 THERMOTOPOGRAPHIC WIND DEVELOPMENT

Variation in radiation receipt and emission by slopes of different aspects and angles is responsible for the initiation of local wind development. Imbalances in the valley radiation regime set up temperature and, therefore, pressure differences both within the valley and against the adjacent plains. Figure 5.1 illustrates the influence of radiation on the development of local winds.

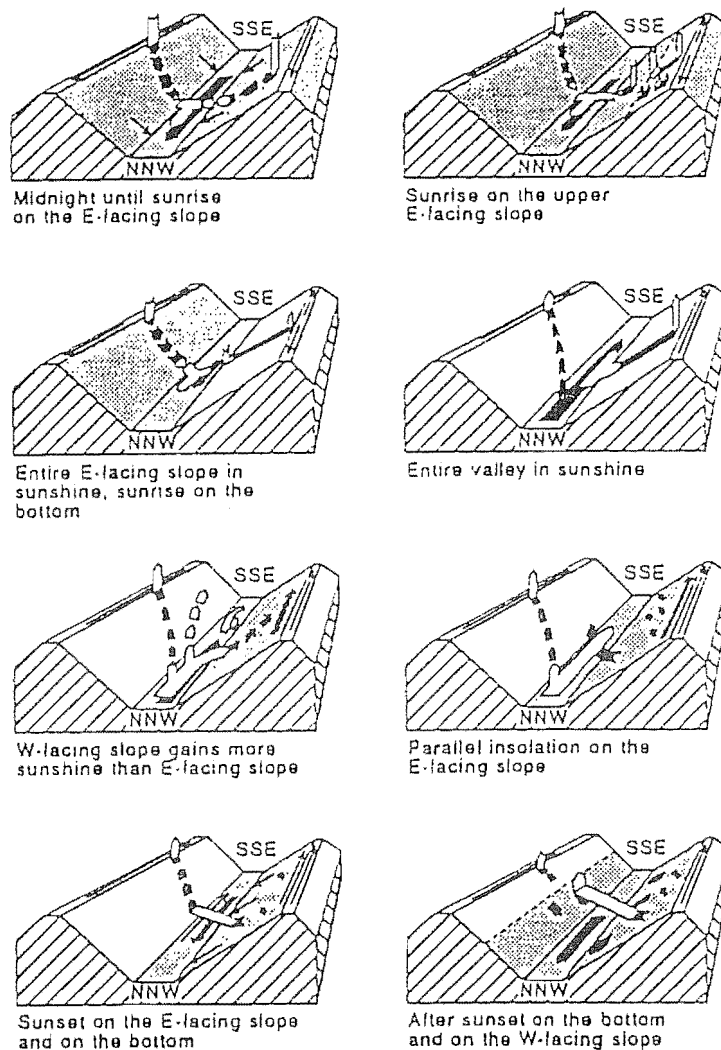


Figure 5.1 The theoretical development of thermotopographic airflow in a valley
(After: Urfer-Henneberger, 1970)

5.2.1 Katabatic wind

During the night, long-wave radiation is emitted from the surface into the atmosphere. Following this loss of energy, the layer of air closest to the surface becomes cooler than the air above. Being cooler it is also denser and responds to gravity by sliding down the sloping surface (Figure 5.2). These winds are typically shallow (2 to 20 m) and the velocities range from 1 to 5 m/s (Stull, 1988). The strength of the katabatic wind depends upon the slope of the surface.

Anticyclonic conditions are most conducive to katabatic development. The associated light gradient winds and clear sky provide for maximum radiative cooling at the surface.

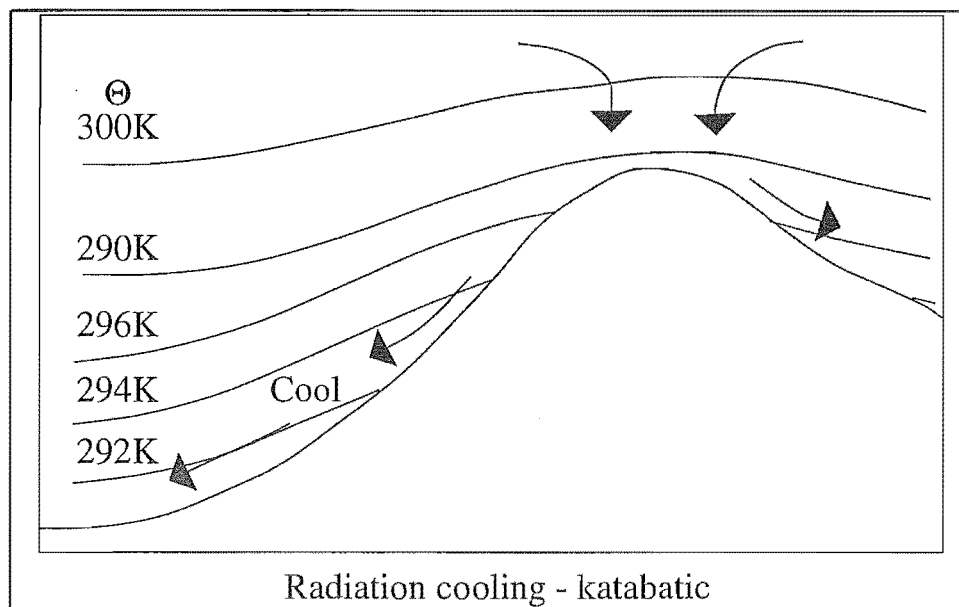


Figure 5.2 Temperature structure associated with katabatic winds

(Source: Sturman, 1987)

5.2.2 Anabatic wind

Following sunrise, the radiation receipt on the valley slopes causes the air above to warm relative to the valley air (Figure 5.3). This air becomes buoyant and

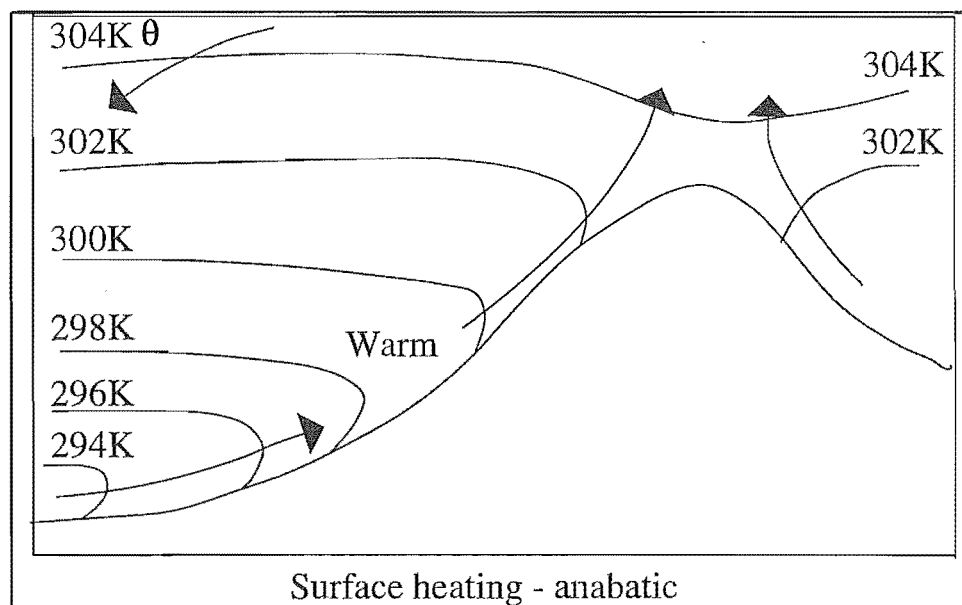


Figure 5.3 Temperature structure associated with anabatic winds

(Source: Sturman, 1987)

risers above the slope causing a drop in pressure that induces a shallow flow up the valley slopes. The development of anabatic flow does not occur over the whole valley simultaneously. Radiant warming of slopes varies with slope aspect and angle and hence, there is variation in onset times on the different slopes.

5.2.3 Sea and land breeze generation

The differing thermal properties of land and water result in contrasting diurnal temperature ranges. The larger heat capacity of water means that sea surface temperatures do not vary much during the day. In contrast, the air above the land heats up during the day, setting up pressure differences. A circulation between the land and sea consequently develops, with air flowing onshore at low levels and air returning to sea aloft (Figure 5.4). At night the circulation reverses, with the land cooling relative to the sea.

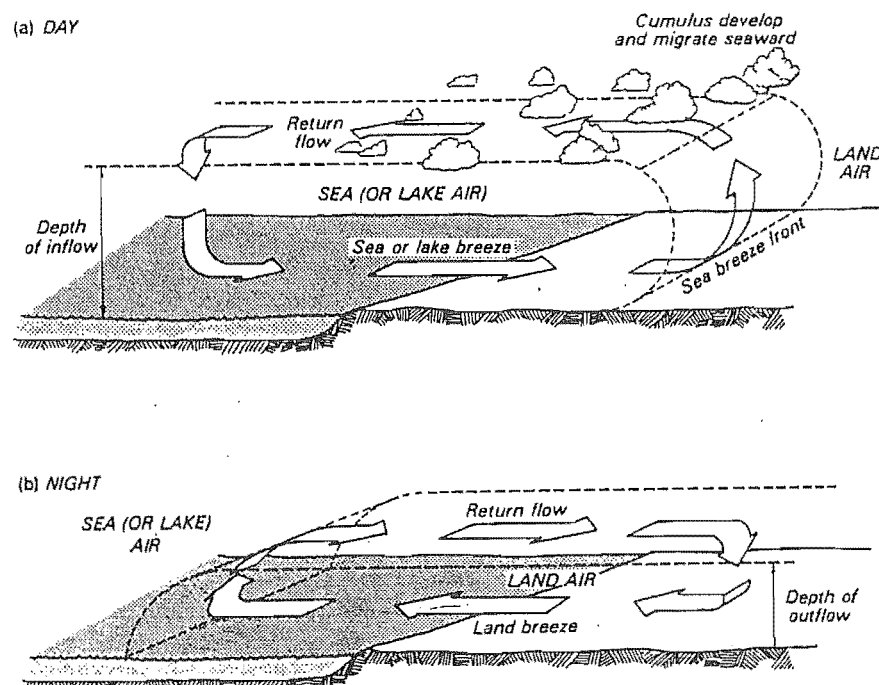


Figure 5.4 Land and sea breeze circulations

(Source: Oke, 1987)

5.3 THE SUMMER WIND REGIME

Nocturnal airflow (0-0900 hrs) in the Horotane Valley is dominated by light winds (< 2.5 m/s) from the southerly quarter (Figure 5.5). The down valley direction of this flow and the corresponding speed, indicate their katabatic origin from the slopes above. Other airflow in the valley is primarily northerly, representing occasions when the gradient flow is dominant.

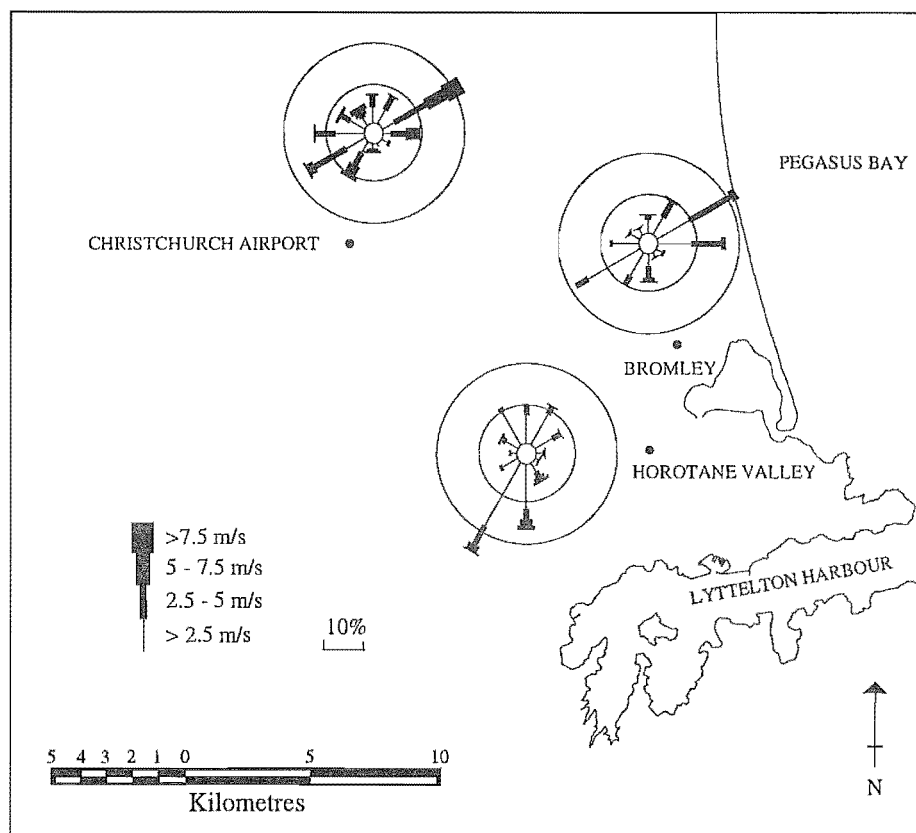


Figure 5.5 Summer - 0-0900 hrs

At Bromley, the corresponding wind is divided between the south-west and north-east quadrants. The south-west flow is typically light (< 2.5 m/s) and is the combination of katabatic flow originating from both the foothills of the Southern Alps and the Port Hills, and the nocturnal return flow of the sea breeze - the land breeze. The original direction of the alpine katabatic wind is modified by the presence of the Port Hills. The nocturnal wind at the Christchurch Airport exhibits similar directional frequencies to Bromley, but are of higher speeds (2.5 to 5 m/s). There are significantly more westerly winds which indicate the unmodified nature of the alpine katabatic flow.

Following sunrise (0900-1200 hrs), there is a significant wind shift in the valley from the south to the north-north-east (Figure 5.6). At the microscale, the air above the east facing slopes is warmed by the sun and begins to rise. This process continues as more of the valley is exposed to incoming radiation and an upslope or anabatic wind develops (< 2.5 m/s). This wind is not only drawn up the valley, but predominantly up the slope exposed to radiant heating. This is the reason attributed to the higher frequency of north-east winds when compared to the insignificant north-west wind. At the meso-scale, this wind is backed by the dominant low level north-easterly, the onset of which tends to occur within 4 hours of sunset (McKendry, 1985). Topographic forcing modifies the direction, resulting in a more northerly component when compared to Bromley and Christchurch.

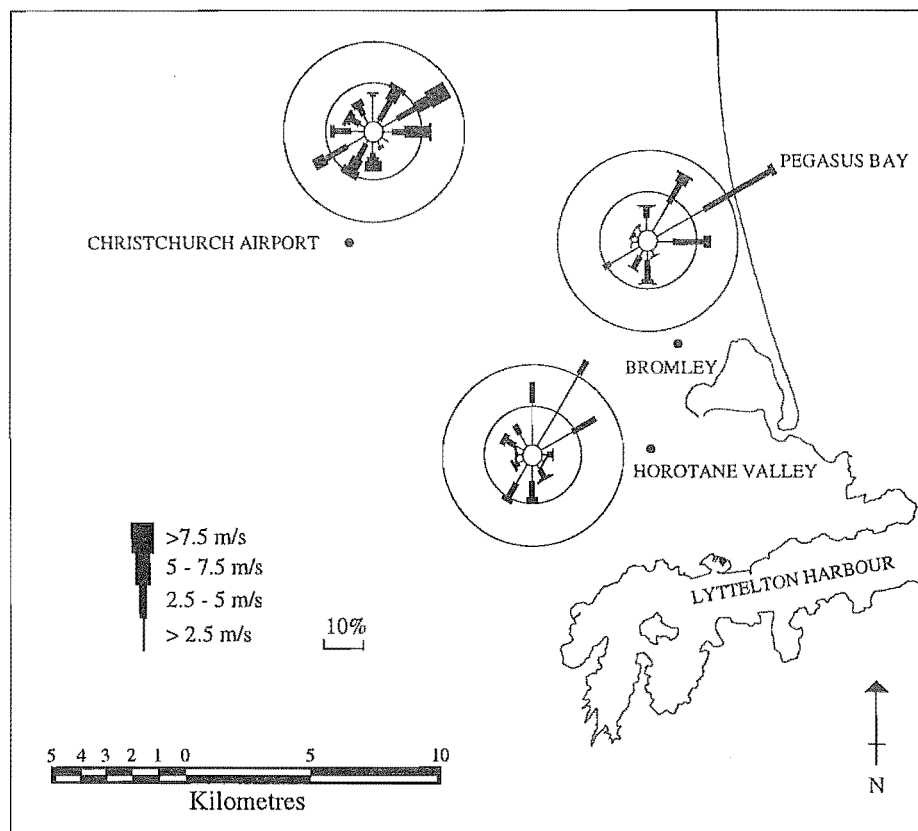


Figure 5.6 Summer - 0900-1200 hrs

McKendry (1985) concluded that the classical sea breeze, generated by a temperature gradient between the land and sea, was not a significant component of the Christchurch wind regime at this time. However, the frequency of north-easterly winds at Bromley for this period, is greater than that at the Airport. This suggests a more localised north-easterly wind, perhaps of sea breeze origin.

Identification of temperature differentials is needed to confirm this as a true sea breeze. Another alternative may be that the north-easterly simply takes time to extend inland and undercut the nocturnal west to south-westerly airflow that exhibits greater frequencies at the Airport.

The Horotane Valley is dominated by north to north-easterly winds in the early afternoon (1200-1500 hrs). These winds constantly fluctuate as the instability of the air increases with localised heating and as small scale circulations develop within the valley. There is a notable increase in winds of north-north-west origin, reflecting the heating of the eastern slope relative to the morning (Figure 5.7). An overall increase in wind speed (to speeds up to 5 m/s) reflects the recognised diurnal variation in speed of the north-easterly wind. The anabatic wind may also be backed by the north-easterly, resulting in an additional increase in velocity. The further increase in north-easterly flow and strength at Bromley (most 2.4 to 5 m/s) and the Airport (2.4 to 7.5 m/s) can be partially attributed to the development of the classical sea breeze. The sea breeze origin of north-easterlies generated in the afternoon was recognised by McKendry (1985).

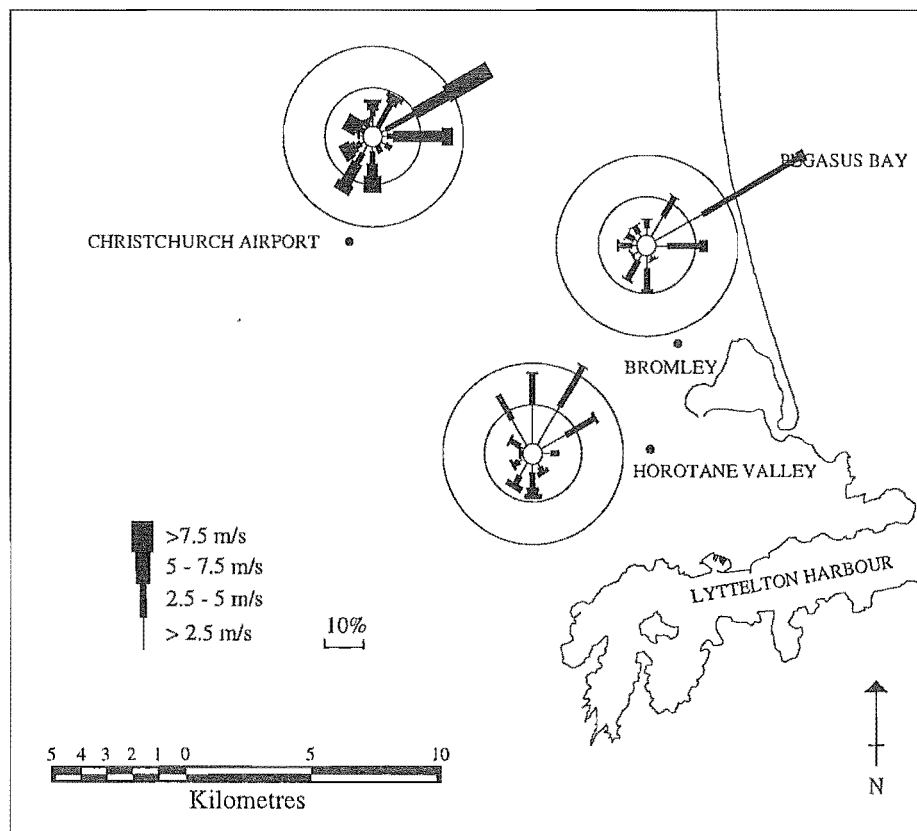


Figure 5.7 Summer - 12-1500 hrs

The late afternoon (1500-1800 hrs) and early evening (1800-2100 hrs) wind regimes in the valley exhibit similar frequencies and strengths as the early afternoon (Figure 5.8 and 5.9). The north-easterly decreases slightly at Bromley but remains constant at the Airport. At both sites, however, there is an increase in the proportion of easterly events. The insignificance of the easterly as part of the afternoon Horotane Valley wind regime reflects the topographic sheltering from and, or modification of the easterly wind, depending on the wind speed. This is also the case with the westerly wind.

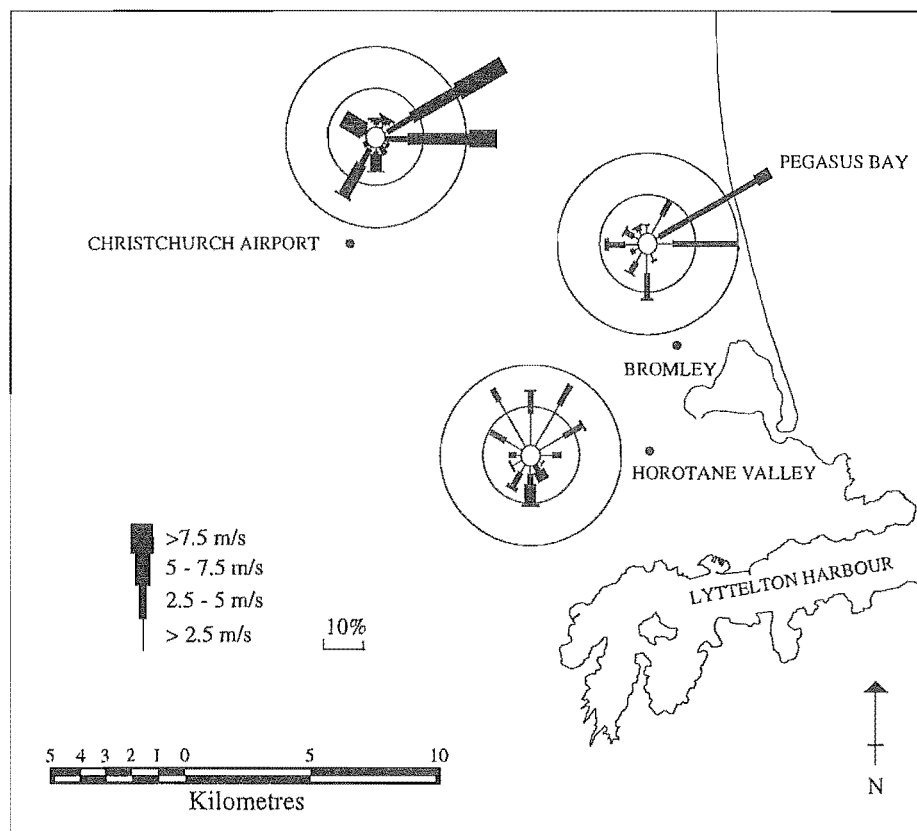


Figure 5.8 Summer - 15-1800 hrs

The evening return of the katabatic south to south-westerly wind in the valley occurs after local sunset (21-2400 hrs) when the boundary layer is able to decouple from the gradient wind (Figure 5.10). The frequency of wind from the northerly quarter and the overall wind speeds in the valley decrease. At Bromley and the Christchurch Airport, the north-easterly remains dominant and there is an increase in south-west winds. The wind speeds similarly decrease at the Airport.

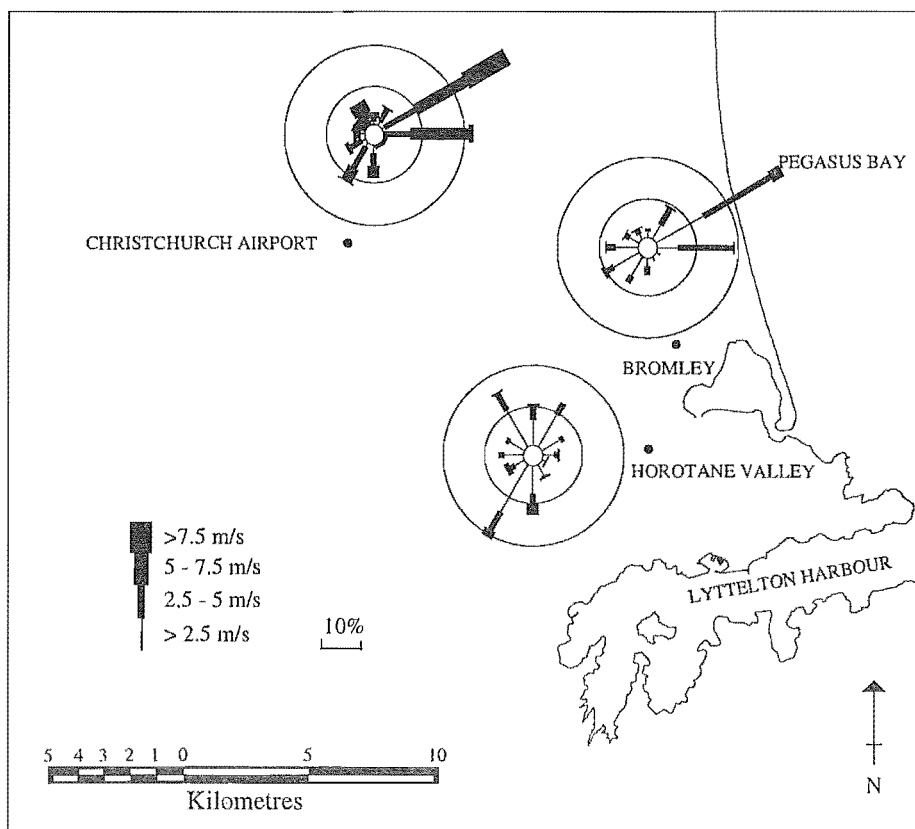


Figure 5.9 Summer - 18-2100 hrs

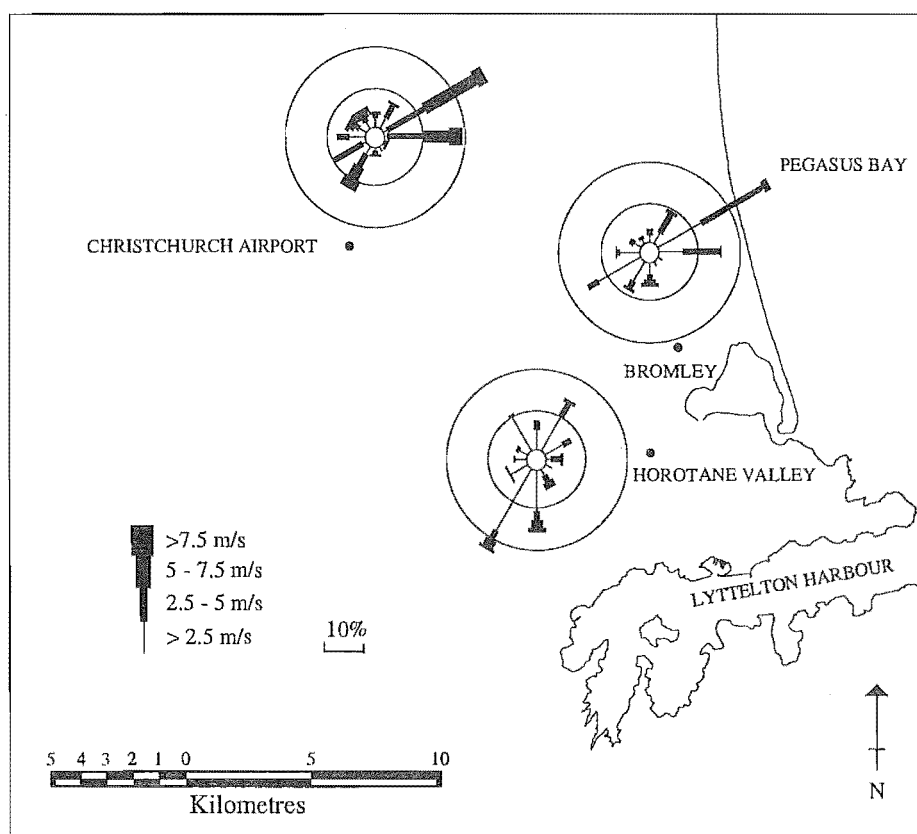


Figure 5.10 Summer - 21-2400 hrs

5.4 THE WINTER WIND REGIME

The development of katabatic winds in the valley at night (0-0900hrs) is more obvious in the winter wind regime (Figure 5.11). The atmosphere tends to be more stable and the seasonal increase in south-westerly winds in the Canterbury region reinforce, rather than mask or obliterate, the katabatic wind. The proportion of nocturnal northerly winds is significantly less than in the summer months, due to general synoptic circulation. At Bromley and Christchurch Airport, there is a similar decrease in northerly winds and an increase in west to south-west winds. The increase in south-westerly wind can be attributed not only to the synoptic circulation, but to the enhanced temperature differential between the land and the sea in these cooler months, resulting in a land breeze. The increased westerly component arises from conditions more conducive to katabatic drainage from the alpine foothills. This wind is characteristically of low velocity and hence, is unable to override the valley topography, effectively eliminating it from the nocturnal wind regime.

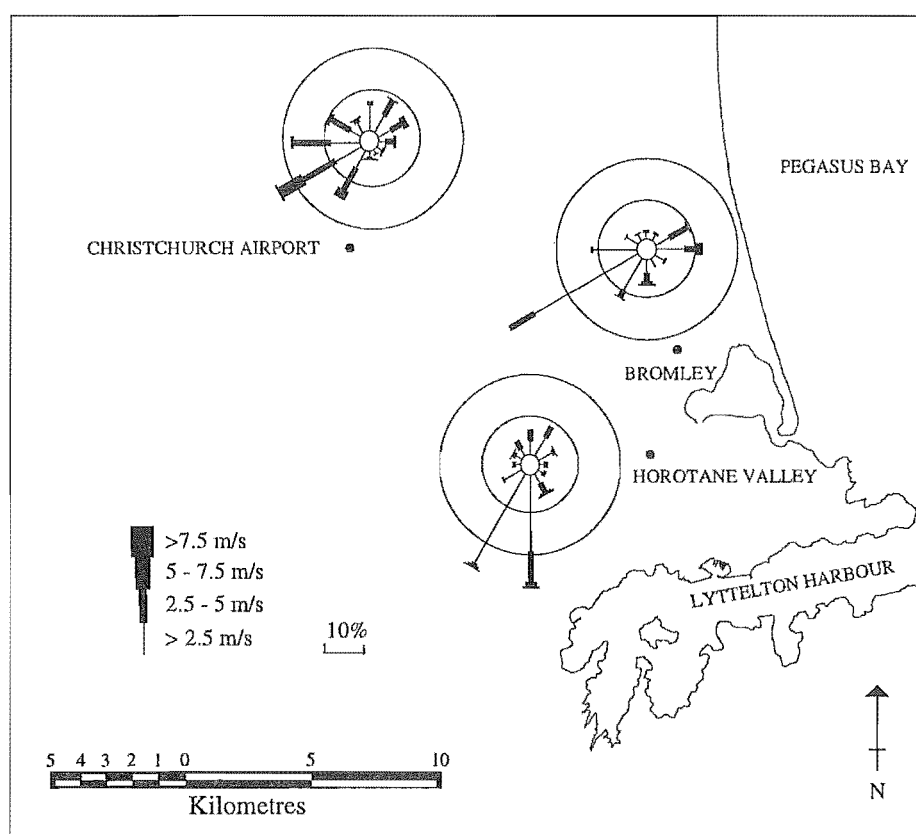


Figure 5.11 Winter - 0-0900 hrs

The north-east anabatic wind in the valley becomes well developed during the morning (0900-1200 hrs). The dominance of this wind over the other northerly directions emphasises the differential heating of slopes in the valley (Figure 5.12). The absence of the north-easterly wind from the other two sites, confirms this is a truly locally generated wind. The southerly winds in the valley decrease slightly but their persistently high frequency throughout the day indicates that they are largely of gradient origin. There is little variation in the wind regime at Bromley and the Airport to that of the previous hours.

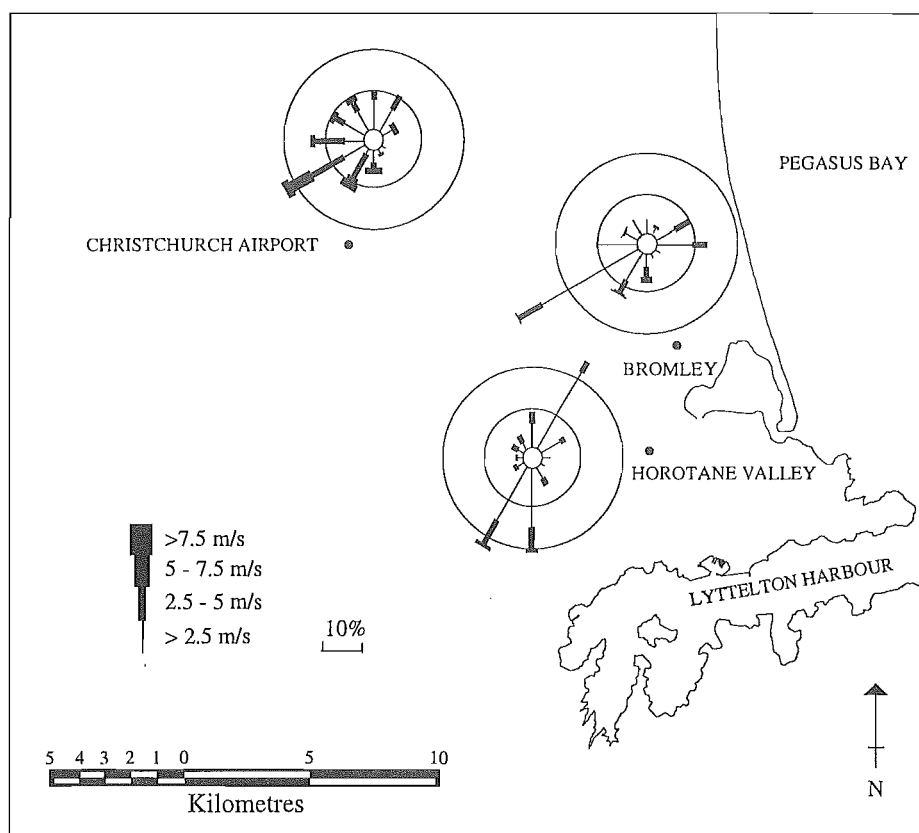


Figure 5.12 Winter - 09-1200 hrs

In the ensuing hours (1200-1500 hrs), the anabatic wind in the valley exhibits more directional variation (Figure 5.13). Winds from all directions in the valley are light (most < 2.5 m/s) when compared to the summer months (more are 2.4 to 5.0 m/s). There is a decrease in southerly flow at Bromley and in the valley, but an increase at the Airport. This may result from the sheltering effect of Banks Peninsula.

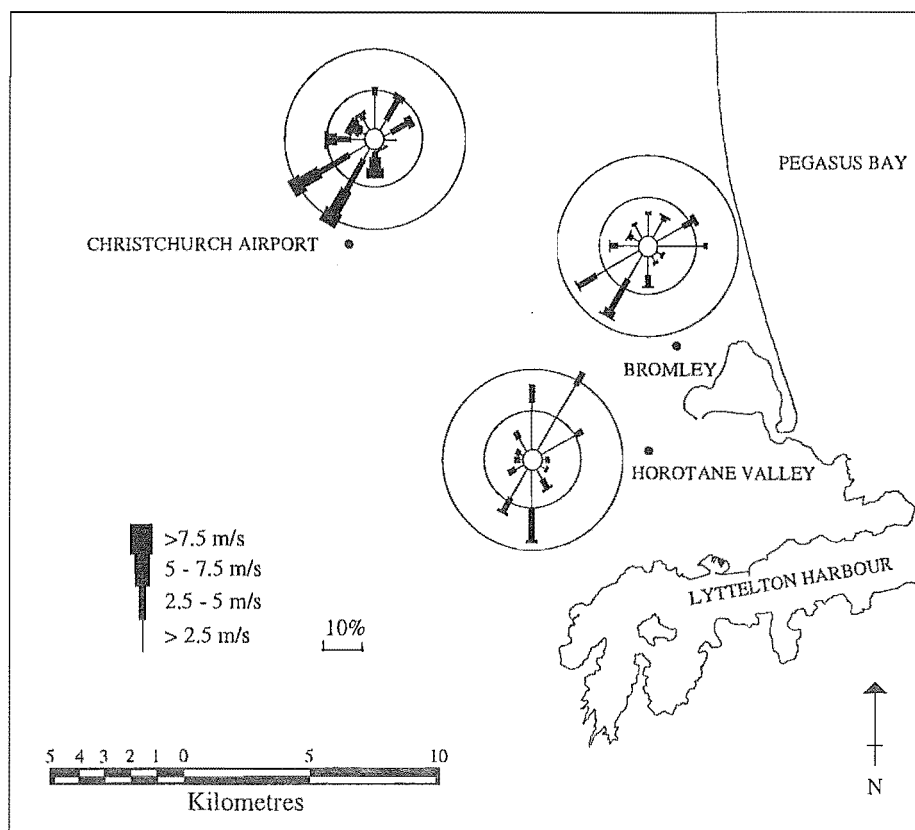


Figure 5.13 Winter - 12-1500 hrs

In the late afternoon, early evening period (1500-1800 hrs) there is a significant reduction in north-north-east flow with more northerly winds (Figure 5.14). There is also an increase in southerly flow, marking the onset of the katabatic wind following sunset. There is a significant south-west component to the katabatic wind at this time, as the air drains off the shaded western slopes first. A slight increase in north-easterly and easterly winds at Bromley indicate that sea breeze development, although reduced, does occur in winter. The extent of inland penetration by the weakened sea breeze is limited, as can be seen by the absence of easterly winds at the Airport when compared with summer.

Following sunset (1800-2400 hrs), the Horotane Valley exhibits similarly high frequencies and speeds of south-south-west wind as the previously discussed evening period (Figure 5.15). The Airport also has a similar evening regime. Bromley, however, develops a large proportion of easterly wind and higher frequencies of westerly wind. With the close proximity of Bromley to the Horotane Valley, the absence of these easterly and westerly winds further reflects the sheltered nature of the valley.

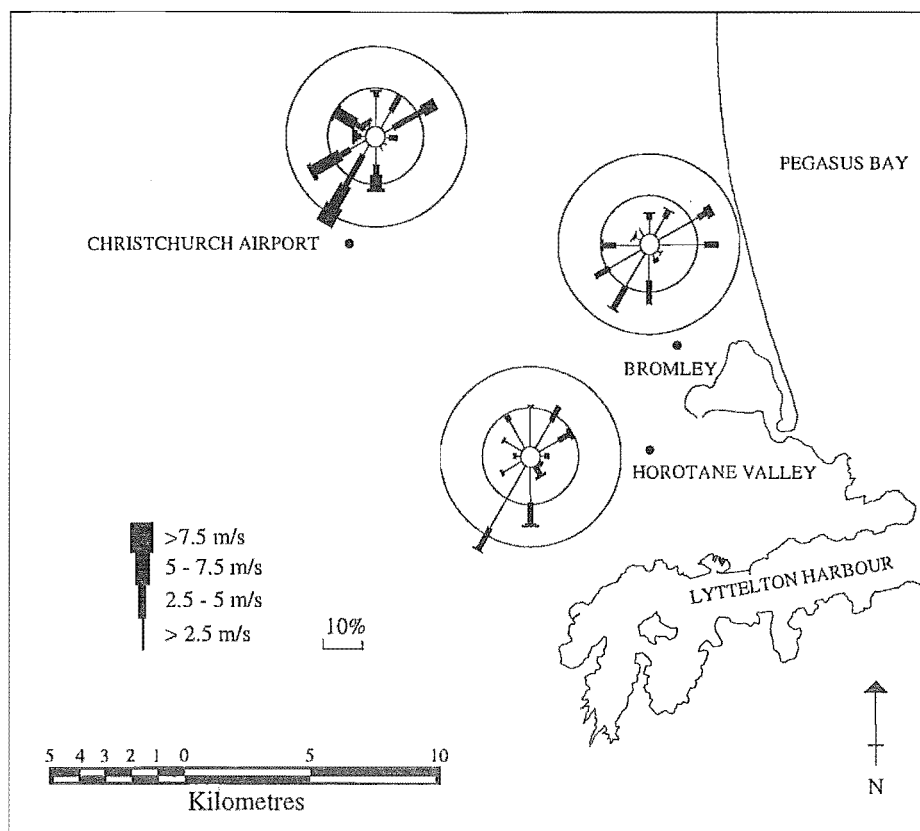


Figure 5.14 Winter - 15-1800 hrs

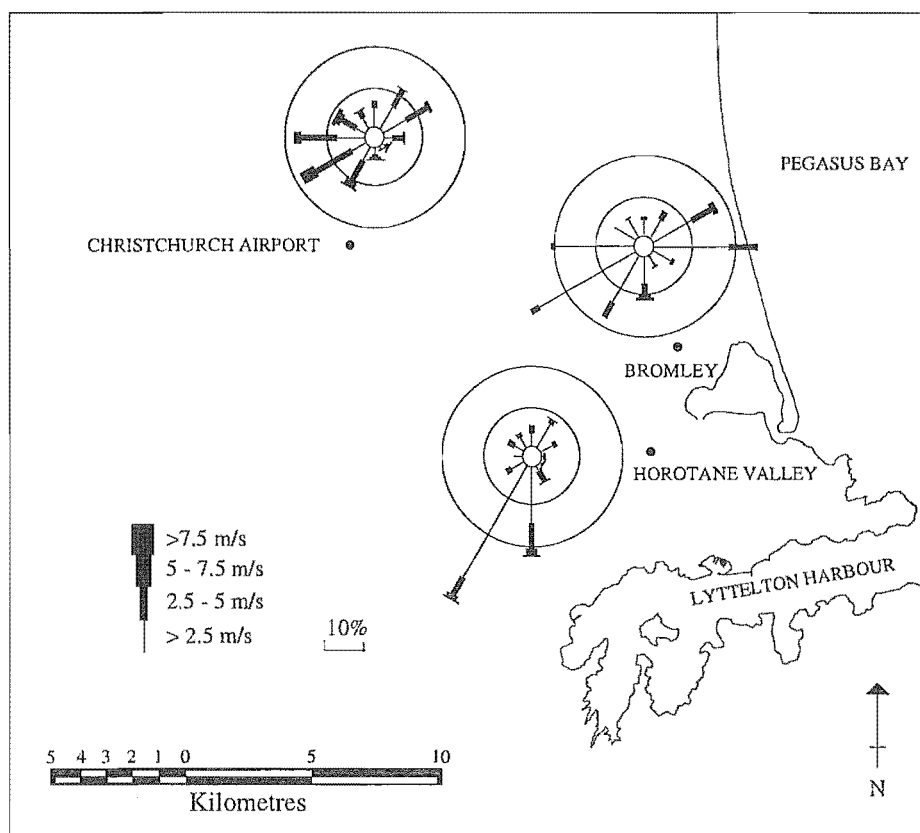


Figure 5.15 Winter - 18-2400 hrs

5.5 IMPLICATIONS FOR LAND-USE

The majority of winds in the Horotane Valley are not of great enough strength to cause mechanical damage to crops. Such damage can occur with windspeeds greater than 8 m/s. The occasional strong southerly gradient wind was found to accelerate down the slopes to reach maximum wind gusts of 15 m/s. This is greater than speeds during similar southerly events at Bromley (10.5 m/s) and the Airport (13.8 m/s). The *Macrocarpa* shelterbelt positioned at the head of the valley is therefore necessary to protect crops from strong winds from this direction. Interestingly, there were no occasions during the study period when winds, other than from the southerly quarter, exceeded 8 m/s. This brings into question the necessity of shelterbelts along the ridgeline of the valley. It appears the topography is enough to shelter the valley from the strong north-easterly, easterly and westerly winds that are present at the Bromley and Airport sites.

Knowledge of katabatic wind development in the valley is useful for the siting of shelterbelts with the objective being to minimise frost risk. A misplaced shelterbelt that is placed perpendicular to the katabatic flow will result in cold air ponding behind it and will therefore increase the frost risk. To minimise the frost risk while still providing protection from the stronger winds, the density of the shelter needs to be low so the wind can flow through it.

5.6 SUMMARY

The wind regime of the Horotane Valley exhibits marked diurnal and seasonal variability. In summer, the Horotane Valley is dominated by winds from the northerly quarter during the day. These winds have a variety of origins including the local, thermally developed anabatic flow; the topographically modified gradient and low level north-easterly wind and the north-east to easterly classical sea breeze. All winds in the valley increase in strength as the day progresses (commonly up to speeds of 5 m/s). At night there is a characteristic change to southerly winds, as the katabatic wind drains cool air off the slopes. The valley is essentially topographically sheltered from winds arriving directly from the east, or west.

During the winter months the same thermotopographically generated winds are present in the valley. Whereas at Bromley and Christchurch Airport the frequency of north-easterly winds diminish, they remain present in the Horotane Valley. This infers that winter conditions are more conducive to anabatic wind development, as the valley atmosphere is more likely to become decoupled from the stable winter atmosphere. Southerly winds become more dominant at all three sites during the day. This is a reflection of the general atmospheric circulation, where a dominance of ambient southerly winds occurs during the winter months. The winter nocturnal wind regime in the valley is similar to the summer months. Southerlies remain dominant in the valley, while at Bromley there is significant proportion of east and westerly winds. With the valley sheltered from these nearby winds, the calm conditions are more conducive to katabatic development.

Investigation of the Horotane Valley wind regime was limited to a five month study period. Although this is not long enough to confidently characterise the wind climate of the valley, it has provided an opportunity to demonstrate the effect of the topography on wind, both by modification of larger scale winds and by the generation of local winds. The wind data can be used to evaluate the necessity of shelterbelts and to identify the appropriate siting for new shelter, bearing in mind the direction of katabatic and strong winds. The effect of the katabatic wind and other larger scale factors on minimum temperature distribution is presented as a series of case studies in the following chapter.

Chapter Six

SYNOPTIC CONTROLS ON MINIMUM TEMPERATURE DISTRIBUTION

6.1 INTRODUCTION

This chapter examines the broader synoptic and meso-scale controls on temperature distribution within the Horotane Valley. Three case studies are put forward to demonstrate the conditions that lead to temperature inversions, development of the normal lapse rate and wide spread frost incidence.

6.2 TEMPERATURE INVERSIONS

The synoptic map from the 25/2/95 (Figure 6.1) shows an anticyclonic system in the Tasman sea, pushing a ridge of high pressure over New Zealand. The isobars over New Zealand are consequently widely spaced, indicating low wind speeds. A cold front lies to the south of New Zealand embedded in a westerly airflow. No active fronts crossed the country during the night.

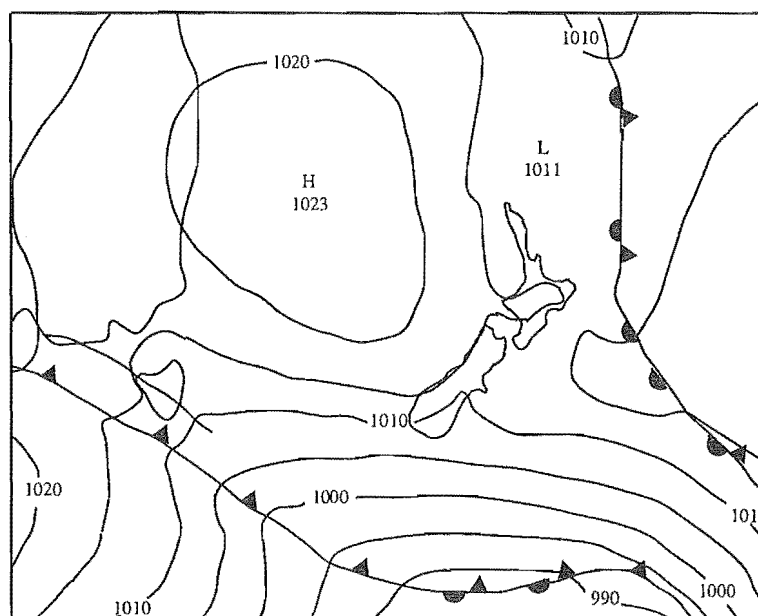


Figure 6.1 Synoptic conditions conducive to inversion development 25/2/95pm

In the Horotane Valley the clear, anticyclonic conditions and associated low wind speeds, initiated the development of katabatic flow. Figure 6.2 clearly illustrates the development of this wind, which is expressed in the valley as a southerly flow that fluctuates between $180 - 245^\circ$ (i.e along the valley axis). On this particular day the onset of the flow occurred one and a half hours after sunset on the flat. Once the radiant input into the valley has ceased, the radiation budget of the valley slopes becomes negative and katabatic flow is initiated. The colder air flows out of the valley or becomes ponded behind obstacles or in depressions. The built up road that closes off one end of the valley may have some influence on this ponding of air on the Horotane Valley floor. Further investigation into the effect of this road would be of direct interest to adjacent horticultural properties.

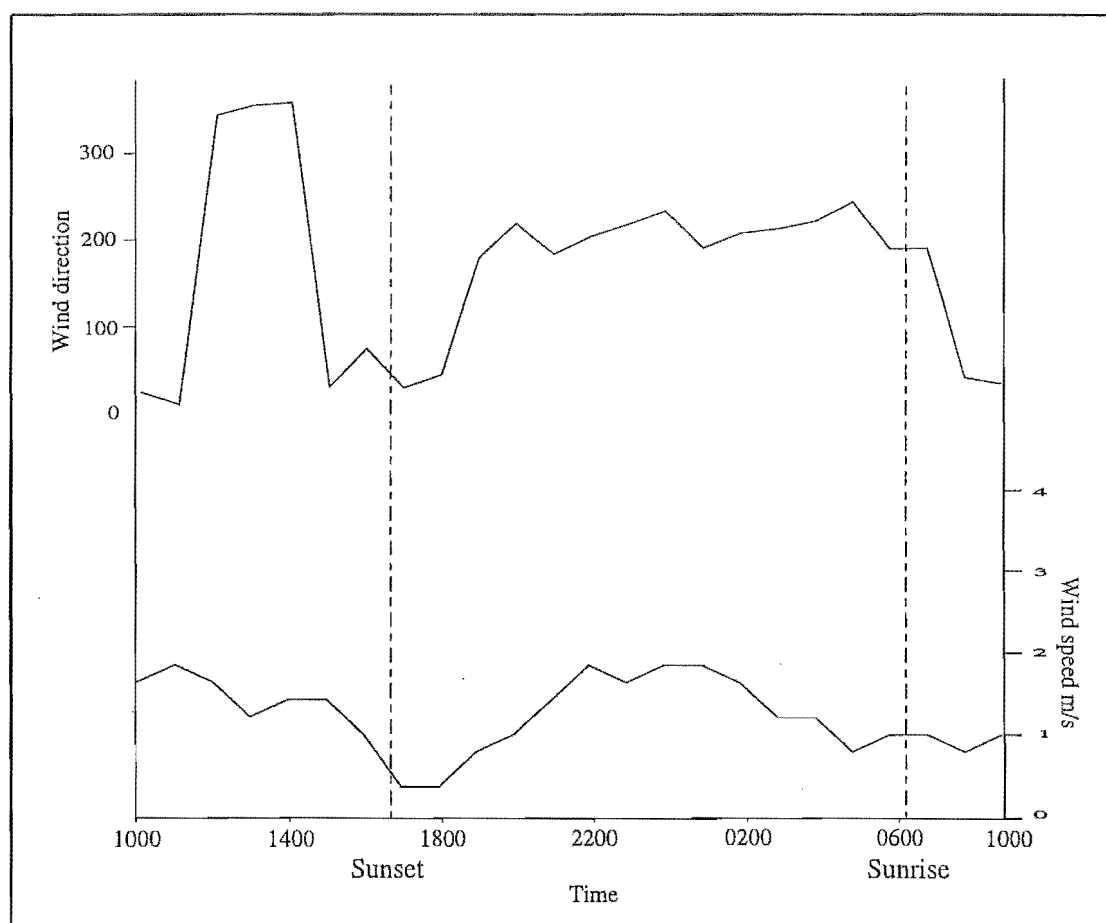


Figure 6.2 Wind speed and direction in the valley 1000 25/2/95 to 1000 26/2/95

In any case, the convergence of the cooler air at the valley floor leads to the development of a temperature inversion. Figure 6.3 illustrates the resultant minimum temperature distribution under such conditions. A clear temperature inversion has developed, with cooler air ponded in the lower reaches of the valley. There is a 6.5°C difference between the minimum temperature at the lowest and highest sites ($3.25^{\circ}\text{C} / 100 \text{ m}$).

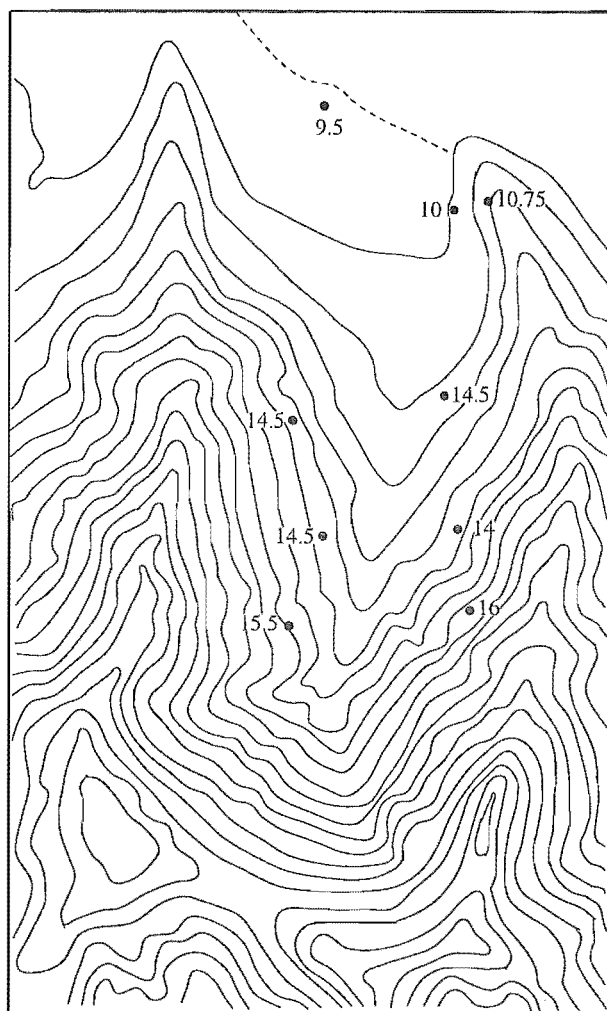


Figure 6.3 Minimum temperature distribution for 25 to 26/2/95

Most of the variation in temperature can simply be related to elevational differences. However, the sky view factor will also be influential. Site 1 is in an open field on the valley floor and therefore is more exposed, while the sky view factor at sites higher up the valley are reduced because of obstruction by the valley walls.

The conditions leading to the inversion development were investigated by analysing data from the valley and nearby Christchurch Airport and Bromley.

At Bromley, an afternoon north-easterly had become easterly by 1700 hrs. The wind persisted until 0200 hrs when it then dropped in strength and became north-west. At the Airport, an easterly breeze developed in the evening around 2300 hrs following a light north-west breeze in the afternoon (2-4 m/s). This easterly wind developed through the night to a peak speed of 7.5 m/s at 0300 hrs. The wind data in the valley did not indicate any airflow from this direction during the night. This confirms one of the conclusions drawn in Chapter 5 - that the Horotane Valley is sheltered from wind arriving from this sector. Under such conditions the valley atmosphere becomes decoupled from the gradient flow, and the potential for katabatic flow and therefore a temperature inversion, becomes enhanced.

Although there was a significant difference in the minimum valley temperatures (6.5°C between the bottom and top sites), there was a smaller difference between the maximum temperature data (1°C difference). On this day, the maximums did not follow a particular lapse rate (Figure 6.4). The maximums appear to be very

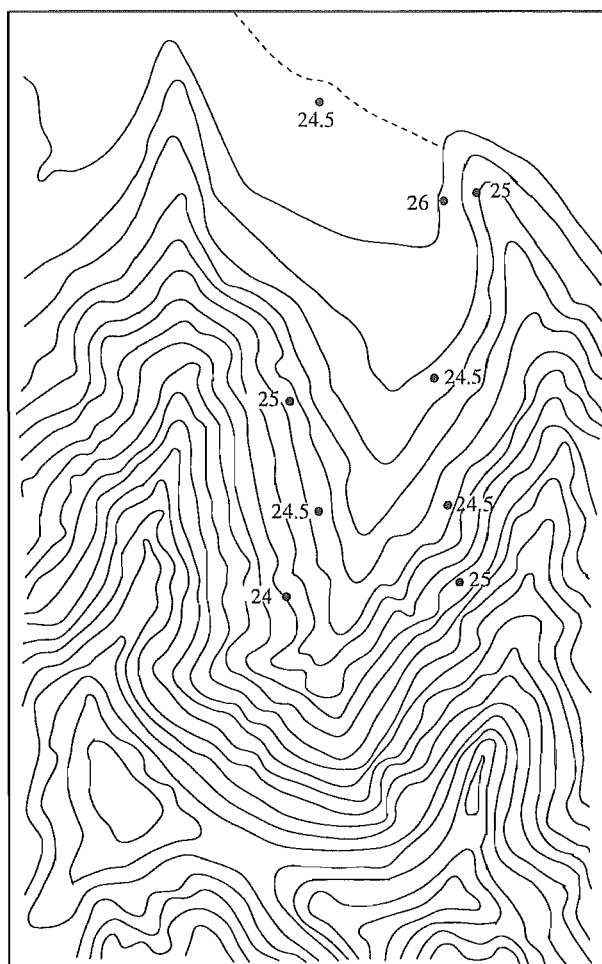


Figure 6.4 Maximum temperature distribution for 25 to 26/2/95

site specific as the temperature both increased and decreased with height. The light diurnal breeze suppressed mixing of the valley air and hence the maximums represent the localised heating of the site surrounds.

6.3 NORMAL LAPSE RATE

The synoptic chart of the 13th March, 1995 (Figure 6.5) illustrates the conditions leading to a normal lapse rate. The weather was influenced by two low pressure systems to the south, which contained a series of fronts that crossed New Zealand through the night. Associated with the unstable atmosphere were high wind speeds (up to 9.5 m/s at Christchurch Airport) and precipitation.

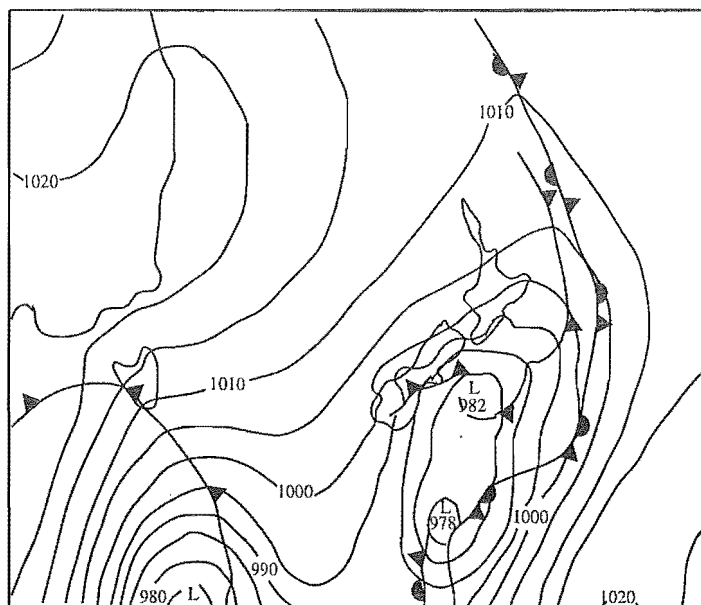


Figure 6.5 Typical synoptic conditions for development of the lapse rate

The wind fluctuated throughout the night between 170° and 200° at the Airport and between 216° and 296° at Bromley. The wind data for the Horotane Valley (Figure 6.6) shows the still afternoon and early evening breeze being interrupted by a stronger north-easterly flow after 2000 hrs (up to 4 m/s). The wind direction altered to southerly after 0100 hrs, that continued at a high velocity (3.5 m/s).

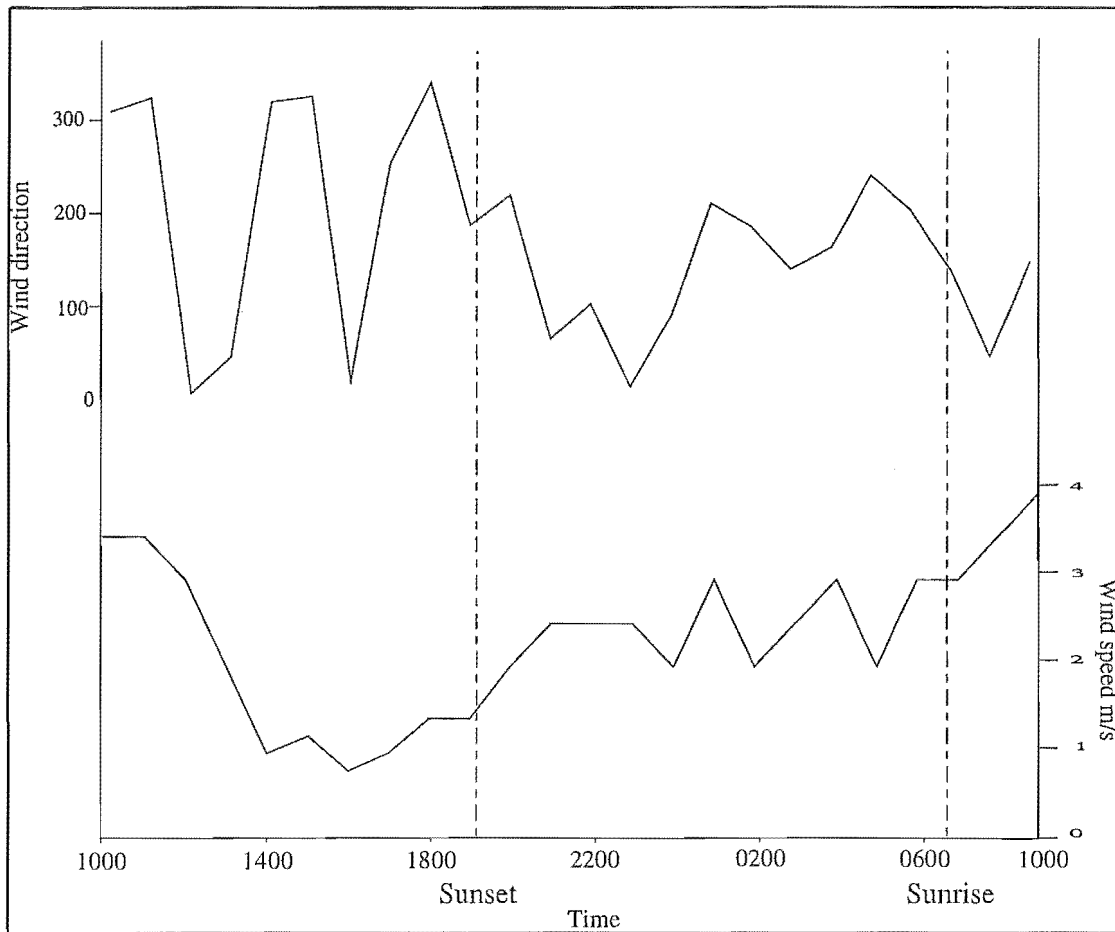


Figure 6.6 Wind speed and direction during the normal lapse rate - 13 to 14/3/95.

The cloud cover limited any significant radiant cooling of the surface, and the strong, fluctuating wind mixed the valley air so as to further inhibit inversion development (Figure 6.7). There was a 1°C difference between the top and bottom sites, which indicates a lapse rate of $0.5^{\circ}\text{C} / 100 \text{ m}$.

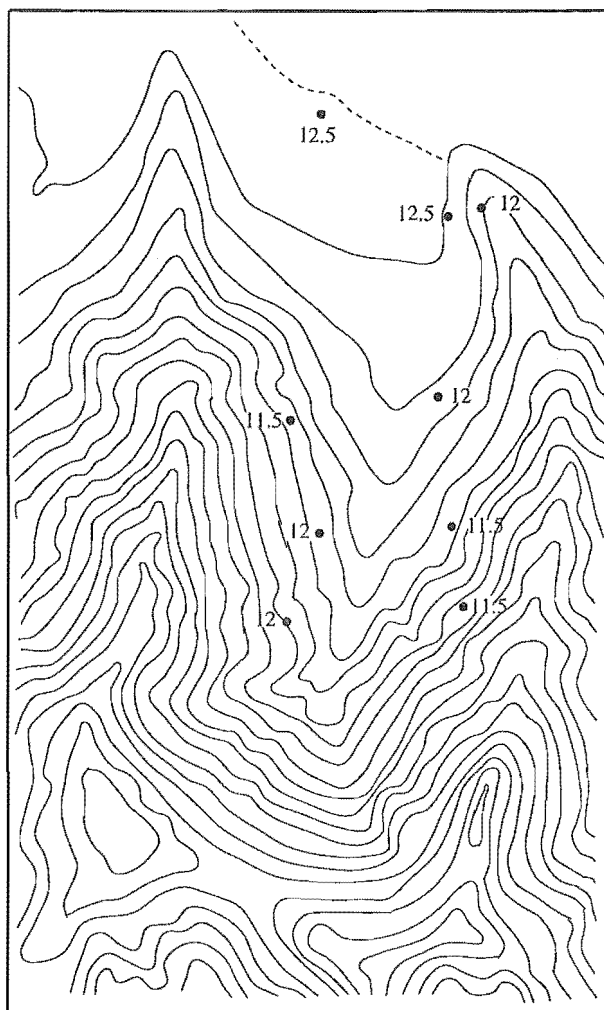


Figure 6.7 Minimum temperature distribution during the normal lapse rate 13 to 14/3/95.

6.4 CONDITIONS FOR FROST DEVELOPMENT

The minimum temperature distribution for the period 1000 hrs (22/6/95) to 1000 hrs (23/6/95) is illustrated on Figure 6.8. This was one of the most severe frosts that occurred during the study period, with Site 1 recording a -3.5°C frost. All the lower sites received air frost, with the higher sites only marginally above the critical 0°C threshold. This section will assess the reason why, on this occasion, most of the higher sites were susceptible to air frost, considering the usual frost events which effect only the lowest site.

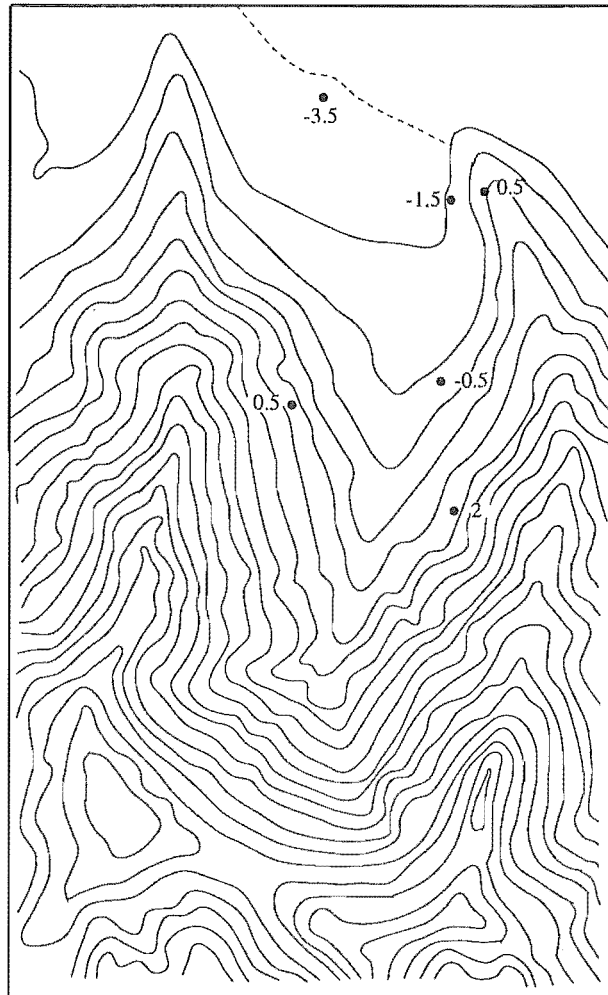


Figure 6.8 Minimum temperature distribution during a well developed frost - 22 to 23 June 1995.

The synoptic chart (Figure 6.9) shows a large high pressure system centred over the east coast of Australia, that extends over the Tasman Sea toward New Zealand. A large low pressure system is centred to the far south of New Zealand. The south west polar air flow associated with the low was channelled up and over the country due to the position of the anticyclone. Consequently, the cooler minimum air temperatures reflect the origin of the airmass. Under the favourable conditions presented by the anticyclone, katabatic flow and a temperature inversion developed. The severity of the frost that developed was due to the low temperature associated with the airflow. The frost could therefore be considered to be of both an advective and a radiative origin.

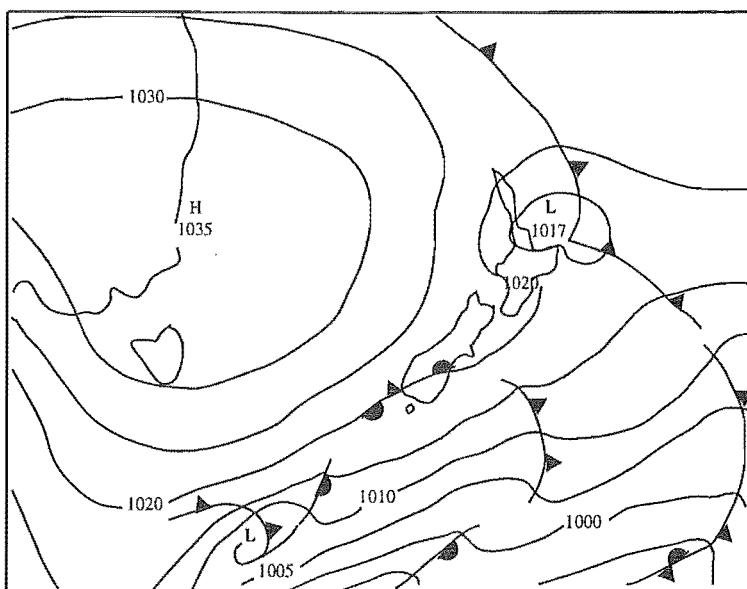
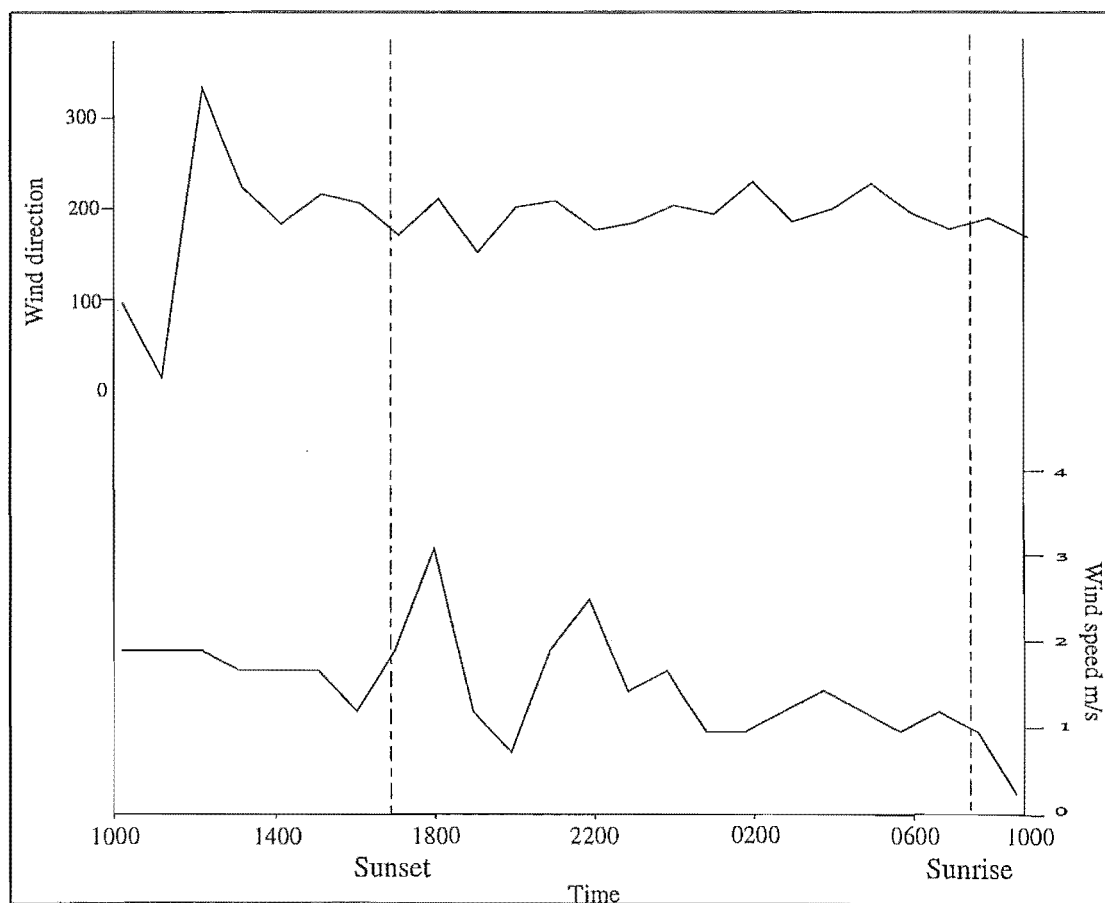


Figure 6.9 Synoptic conditions that lead to frost development

The conditions at the other Christchurch sites confirm what the synoptic charts infer. The wind speeds at the Airport were low during the day and night (0-3 m/s), while the wind fluctuated between the east and south-west quarter.



6.10 Favourable wind conditions for frost development

The wind at Bromley was consistently from the south-west quarter (190-256°) and was of similarly low speeds (0-3 m/s) during the night. The low wind speed enabled katabatic wind development and the cooler south-west wind provided a lower base temperature for radiative cooling to begin. The wind data (Figure 6.10) shows the light north to north-east (350-45°) breeze that developed in the valley during the day which became southerly after the local sunset.

6.5 SUMMARY

The three case studies put forward in this chapter clearly indicate the importance of synoptic scale controls on minimum temperature distribution within the Horotane Valley. Anticyclonic conditions are conducive to inversion development, and the presence of nocturnal easterly or westerly winds also favour their propagation. A well-mixed atmosphere, promoted at the synoptic scale by the passage of fronts and the strong gradient winds, inhibits the development of the temperature inversion. Minimum temperatures then follow the normal lapse rate. Anticyclonic conditions enhance the possibility of frost occurrence, with the associated clear skies and light winds resulting in maximum radiative cooling. Gradient winds from the south decrease the temperature of the airmass, and make frost development more likely. The following chapter draws together the microclimate data to investigate the suitability of the valley for growing kiwifruit, grapes and stonefruit, such as apricots.

Chapter Seven

MICROCLIMATE AND LAND-USE IN THE HOROTANE VALLEY

7.1 INTRODUCTION

This chapter investigates land-use potential in the Horotane Valley by drawing on the findings of the previous chapters. Consideration is primarily given to the thermal regime as this is a major controlling factor of horticultural activity. Knowledge of solar radiation patterns and the wind regime provide an extra insight into the appropriate growing areas. The physical limitations imposed by slope and soil type on land-use development are also discussed. Finally, the suitability of the valley soils and microclimate for growing crops such as kiwifruit, grapes and stonefruit are discussed.

7.2 THE MICROCLIMATE OF THE HOROTANE VALLEY

The uniqueness of the Horotane Valley microclimate has been outlined in the preceding chapters. The topography of the valley is primarily responsible for the climatic differences between the Horotane Valley and the adjacent Canterbury Plains. This section summarises the characteristic climatic variables that constitute the valley microclimate and the implications they have for land-use.

7.2.1 Radiation

Radiation receipt within the valley varies according to slope angle and aspect. This results in the differential heating of the various slopes. Not only is this important for generation of the thermal conditions required by plants, but also for the initiation of thermally developed winds in the valley. In the summer

months when the sun is high in the sky, a lower north-west facing slope of 30°C will receive 6% less solar radiation than the valley floor. In contrast, the sloping surface will receive about 46% more in the middle of winter when the sun angle is low.

The length of time that solar radiation is received also varies within the valley. Different plant species have different daylength requirements, and a widely used measure for classifying the requirements is bright sunshine hours. At various locations within the valley, the shadows cast by the valley walls limit the length of time exposed to this radiation. The east facing slopes receive the sun earlier than the west facing slopes and therefore photosynthesis is initiated earlier. However, they also lose the sun earlier in the day and consequently photosynthesis ceases earlier. The upper reaches of the valley floor are subjected to shading also. The valley floor in the lower reaches is wide and the valley walls low, and hence, it is not effected to the same extent by shading so the radiation regime tends to be more reflective of the surrounding plains because of the horizontal nature and unobstructed skyline.

The shelterbelts that run along the north/south ridges of the lower eastern and western slopes, effectively extend the slope height and therefore the length of time the slope is in shade. Solar radiation levels are additionally reduced to 20 % to a distance of one shelterbelt height and 10 % at two shelterbelt heights (Kerr *et al.*, 1987). Consideration is given to the need for these shelterbelts in section 7.2.3.

7.2.2 Thermal regime

Temperature influences the growth of plants both daily and seasonally by the control it exerts over metabolic processes. There is an optimum temperature range that for plants that varies according to species.

Growing degree days and chill units are an expression of horticultural growing potential that represent the accumulation of time spent at or within a specified temperature range. GDDs represent the amount of time spent above the

minimum temperature that is needed to reach maturity during the growing season. GDDs were found to initially increase with increasing elevation, from a low of 963 on the valley floor to a high of 1201 at 50 to 60 m. This increase in minimum temperatures with creasing elevation results in more time spent above the required temperature threshold and hence the greater accumulation. Above 50 to 60m GDDs decrease as lower maximum temperatures counteract the higher minimums.

GDDs are accumulated during the growing season which begins when sufficient chill units have been accumulated. A certain degree of chilling is required by many plants before dormancy can be broken and flowering initiated. This is particularly true of deciduous fruit trees, where insufficient chilling can lead to delayed growth and ripening of the fruit. High accumulations of chill units were found on the valley floor (2361) and they decreased with elevation to a minimum at a height of 100 m on the eastern slopes and 125 m on the western slopes. Above this height they began to increase once again.

The topographic nature of the valley is responsible for the resulting temperature regime. This is partially due to the effect on radiation receipt and maximum temperatures but primarily by the controlling effect on minimum temperatures. Generation of nocturnal katabatic winds by radiative cooling of the slopes results in cold air ponding on the valley floor, with a consequent increase in minimum temperature with height. A thermal belt may exist at the top of this inversion layer, however, this was not identified during the field period. This thermal belt would be an ideal area to locate frost sensitive plants that require high temperature levels. Temperature inversions are common in the valley and are associated with clear skies and a calm atmosphere. The winter months are more conducive to inversion development due to the general synoptic circulation.

Frost is a common occurrence on the valley floor during the winter months. Frosts are most frequent below 20 m but do occur to a height of 60 to 80 m. Above this height minimum temperatures are sufficiently high as the katabatic flow off the slopes drains cold air onto the valley floor. Caution must be taken in the siting of shelterbelts to ensure they do not impede the katabatic drainage from the slopes. Ponding of cold air is likely to occur behind dense shelterbelts

and other obstacles and increase the frost risk.

7.2.3 The wind regime of the valley

Wind may physically damage a plant and its fruit, or it may be responsible for deformation of its shape. The north-west and south-west winds are primarily responsible for damage to crops on the plains and the human response has been to erect shelterbelts. The wind regime of the Horotane Valley appears vastly different from that of the Christchurch Airport, which can be considered to be representative of the surrounding plains.

The Horotane Valley has a distinct wind regime that is largely the result of thermotopographically winds generated in the valley. Winds exhibit a marked daily and seasonal variability. Diurnal winds are dominantly northerly - ranging from 315 to 75° with average speeds of less than 2.5 m/s that peak in the afternoon at 5 m/s. These are a combination of anabatic winds, the sea breeze and the prevalent low level north-easterly. Katabatic winds dominate both the summer and winter nights. These are typically light (< 2.5 m/s) and are expressed in the valley as southerly winds (160 to 210°). In winter the katabatic wind is often backed by the seasonally prominent south-westerly. This increases the subsequent windspeed of the nightly drainage flow. The southerly reached speeds of up to 15 m/s during the study period indicating that the existing large shelterbelt that protects the upper valley is justified in its location. Any development further beyond on the pastoral land would need further shelter from the high velocity southerlies. The valley may be exposed to high velocities from the south but occurrences of wind from the east and west are insignificant in the upper valley. The valley is topographically sheltered to winds from these sectors and the necessity of ridgeline shelterbelts must be questioned.

Care must be taken with the siting of shelter between adjacent properties. The katabatic wind flows should be carefully considered to identify areas susceptible to cold air ponding. Alternatively, new shelterbelts should be of a low density to avoid impedance of the flow.

7.3 OTHER PHYSICAL CONSTRAINTS ON LAND-USE

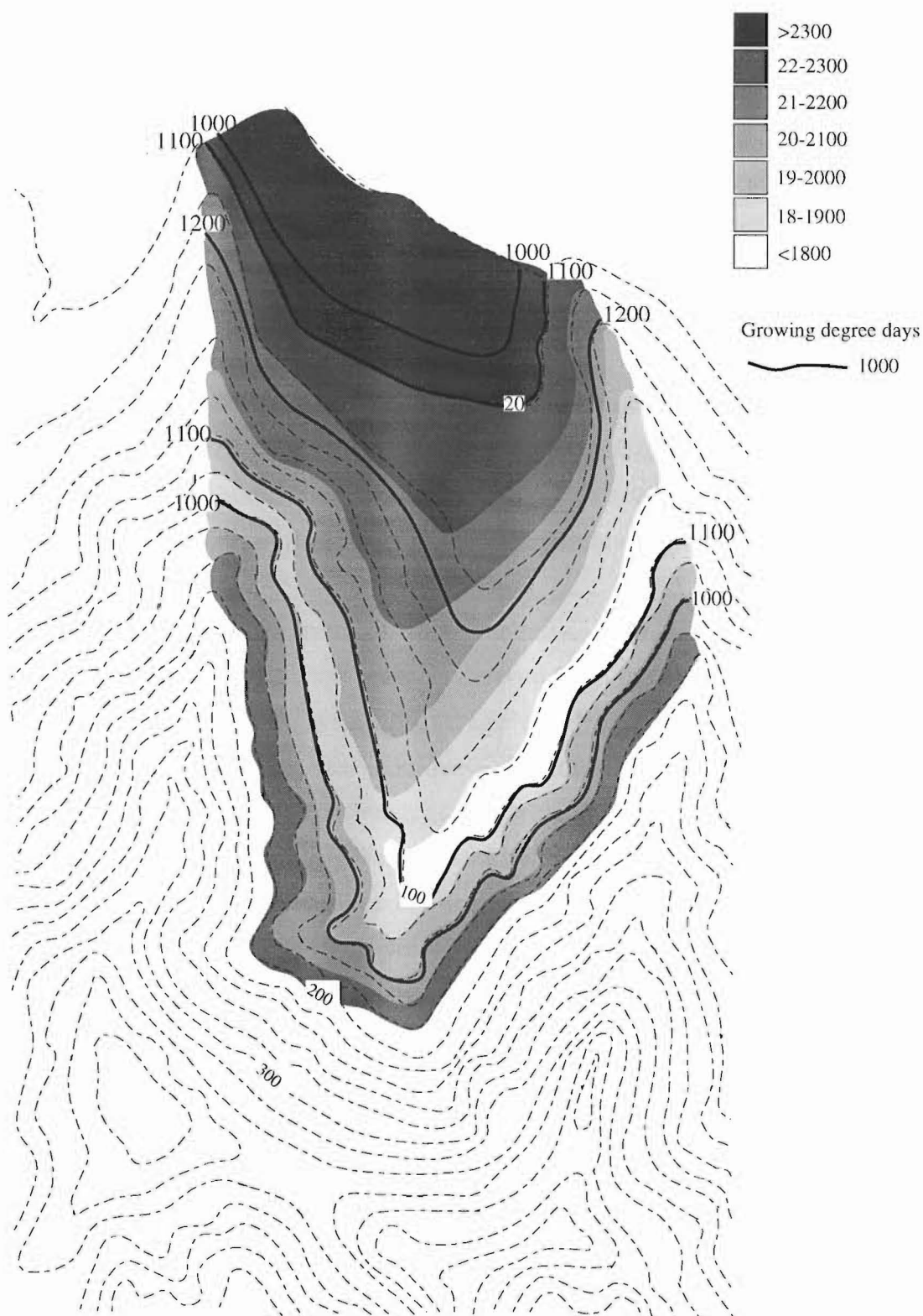
The soils of the Horotane Valley are not considered as productive as the intense horticulture on the land above would suggest. The soils of the Horotane Valley are primarily loessial or volcanic and the moisture retaining capacity, nutrient status and susceptibility of the soils to erosion are recognised limitations to development (See Appendix 1). The soils of the valley floor are not prone to erosion due to the low slope angle. They are, however, recognised as having a low nutrient status and poor internal drainage. The lower slopes of the valley are formed from loessial soil and also have very slow internal drainage and become waterlogged very quickly. Tunnel gullying is the resultant form of erosion that is commonly seen because of this impeded drainage. The tunnels can undermine roads and buildings and be hazardous to stock. Those soils with a higher volcanic content have higher natural fertility and better internal drainage. Unfortunately, these soils are shallow and are located on the upper, steeper slopes of the valley. Due to the layered structure of soils like the loess colluvium erosion occurs through tunnel gullying and debris flows.

The land previously used for extensive sheep and cattle grazing would require soil rehabilitation subsequent to any horticultural development. The tunnel gullying is extensive on the lower slopes and there is evidence of debris flows of varying sizes. The nutrient status of the soils could be enhanced by fertilizer but the moisture retention problems must also be addressed.

7.4 LAND-USE OPTIONS FOR THE HOROTANE VALLEY

This section explores the possibility of growing crops that are either considered unsuitable or marginally suitable for commercial growth in the Canterbury climate - kiwifruit, grapes and stonefruit. Identification of suitable areas can be achieved by incorporating the thermal regime, radiation distribution, soil types and erosion risk into a Geographic Information System (GIS). For this thesis however suitable areas were identified by subjectively matching crop requirements with the findings of this research. Unfortunately specification of

required chill units and GDDs were often absent from publications that only presented descriptive requirements. Finally, the present land-use in the valley is evaluated to see if it is optimising the potential. Figure 7.1 indicates the patterns of GDDs and chill units within the valley.



7.1 Growing degree day and chill unit distribution in the Horotane Valley

7.4.1 Kiwifruit

The main production area for kiwifruit in New Zealand is the Bay of Plenty, with Blenheim and Nelson the dominant producers in the South Island. Kiwifruit require 50 to 100% more photosynthetically active radiation than most other crops and hence would grow better on the lower angle slopes that receive greater levels of radiation in summer.

Cool winter temperatures with chill units exceeding 1200 are required to induce bud break in spring (Salinger *et al.*, 1993). Kiwifruit is also sensitive to screen frosts between mid-September and mid-May. Warm spring and summer temperatures are required with 1100 GDDs needed during the growing season (Kerr *et al.*, 1987). In the Horotane Valley the thermal requirements of the kiwifruit are met between elevations of 20 to 120 m. Although frosts are at a maximum below 20 m, they do occasionally extend to heights of 80 to 100 in winter. The likelihood of spring and autumn frosts within the optimal thermal range is minimal, as autumn frosts in the valley did not occur over 20 m.

Kiwifruit require 1250 mm of rain annually, with 100 mm/month during December to March. Rainfall normals derived from the Horotane Valley put the yearly total as 709 mm, with an average of 51 mm/month over the summer period (N.Z Met. Service, date unknown). Deficits can be made up by irrigation. The poor internal drainage and water retentive nature of the soils in the Horotane Valley would be a limiting factor to kiwifruit development as the vine is sensitive to water excesses. The kiwifruit is also susceptible to wind damage so shelter from the southerly winds would be necessary.

7.4.2 Grapes

The Christchurch region was deemed marginal for grapes by Hurnard (1982) mainly due to inadequate GDDs. A cool climate grape such as Riesling, requires between 1000 and 1250 GDDs and the average GDD total for the Christchurch Airport is only 941. These requirements are however met in the Horotane Valley

at heights greater than 15 m and up to 160 m. This range encompasses approximately half of the valley. The low chilling requirements of grapes are easily met in all parts of the valley. Additionally, a frost free season of greater than 180 days is exceeded throughout the entire valley. The grapes require the mean temperature of the warmest month to exceed 17.5°C. Although not specifically calculated for the valley, the Christchurch mean monthly temperature for January is 16.5° (N. Z. Met. Service, 1983). A high correlation was shown to exist between Christchurch and the valley temperatures (Appendix 2c) so the valley can similarly only be thought of as marginal in terms of mean monthly temperature during January. High sunshine hours also improve the quality of the wine and therefore slopes of lower angle are more likely to be suitable.

The rainfall of the valley (709 mm) is more suited to grapes than kiwifruit, as preferred areas for viticulture have less than 900 mm annual rainfall. The water retentive soils remain a concern as wet conditions in late summer and early autumn decrease the quality of the vintage and also promote root rot.

7.4.3 Stonefruit

Stonefruit includes crops such as the apricot, plums, cherries and nectarines. These fruits have traditionally been grown in the Horotane Valley. Canterbury is not considered as a major commercial growing area of stonefruit, with Marlborough and Central Otago the largest South Island growers. These deciduous fruits, and especially the apricot, require high levels of winter chilling to break bud dormancy by comparison to other fruit (900 to 1500). These levels are exceeded in all parts of the valley. Areas where early spring frosts (September) are likely to occur must be avoided as this is the time when the stonefruit flower. September frosts do occur at the Christchurch Airport so it can be assumed that they would also occur on the valley floor. For this reason it is suggested that stonefruit be sited above 20 m. The GDD requirement of apricots (800 GDD) is exceeded in all parts of the valley.

The relatively low rainfall of the valley (900 mm) is theoretically suited to

growing fruit of this type, as annual rainfall in excess of 1000 mm can increase the risk of fruit splitting and disease. As with Christchurch, rainfall has a winter maximum in the Horotane Valley, with an average summer rainfall of only 51 mm/month.

7.4.4 Present land-use in the valley

At present the majority of the valley that is already under horticultural use is being used to its potential. The valley floor is predominantly used for greenhouse crops and outdoor vegetables. The greenhouses can be heated to counteract any effect of frosts, whereas the vegetables are either frost hardy or harvested before the winter. These are probably the best options for the valley floor, which has the highest frost risk.

Although the land owners in the valley are growing stonefruit on the lower valley slopes, there has been no expansion from the traditional crops of apricots, plums and cherries. This research has shown that the valley climate could support other marginal crops such as kiwifruit and grapes.

The upper slopes and head of the valley are currently used for extensive sheep and cattle grazing. This land was historically part of a large run holding that included the adjacent valleys but it was recently sold. The new owner continues to graze sheep and cattle on the slopes of the valley. This land is the most under-utilised in the valley as the lower slopes are suitable for orcharding and other high value horticultural activities. Additional shelter would be necessary to protect crops from the southerly winds.

7.5 SUMMARY

The focus of this chapter has been to bring together the elements of the microclimate and knowledge of the other physical properties of the valley to establish areas that are suitable to certain crops. The thermal requirements of kiwifruit are met throughout the valley. As kiwifruit are sensitive to autumn and

spring frosts they are best planted above 20 m. Deficits in their water requirements can be made up by irrigation. The dry valley summers are suited to grapes and stonefruit as they are susceptible to root rot and fruit splitting. The thermal requirements of grapes are met between 15 and 160 m, although the mean January temperature is not above the required 17.5°C. Stonefruit may be grown anywhere above 20 m to avoid the Spring frosts. In all cases shelter from the strong southerly wind is necessary to prevent damage to the fruit.

The present land-use in the valley was assessed evaluating the climate for crops traditionally considered unsuitable or marginal. The potential of the valley floor is limited by the high frost risk, and therefore, the present greenhouses and outdoor vegetables can be considered as suitable land-uses. The majority of the lower valley slopes are already planted with stonefruit, however, there is the possibility that other crops such as grapes and kiwifruit could also be grown. Parts of the upper valley that are currently used for sheep and cattle grazing have been identified as suitable for stonefruit, grapes and kiwifruit although additional shelter would be necessary. Therefore this research has shown that crops considered marginally suitable or unsuitable for commercial growth on the Canterbury Plains, are theoretically suited to the microclimate of the valley.

Chapter Eight

CONCLUSIONS

This thesis has presented a detailed account of the microclimate of the Horotane Valley that can be used to determine land-use suitability. The objectives of this thesis were achieved using a combination of observational and modelling approaches.

Three case studies of short-wave radiation were presented that gave a first approximation of the variation in radiation receipt caused by the slope angle and aspect. Calculation of the corresponding albedos gave an indication of the controlling effect of the surface characteristics. The uniformity, colour and moisture level of the surface were all influential on the albedo. Modelling using the "Cosine Law of Illumination" illustrated the seasonal variation of the solar radiation distribution for various slopes. The modelling overestimated the amount of short-wave radiation as the model did not take into consideration cloud cover, air pollution and the effect of the sky view factor.

Maximum and minimum temperature data were collected over a five month period. A wide variety of temperature scenarios were sampled as the collection of temperature data began in late summer, continued over autumn and ended in early winter. Correlation analysis of the valley temperatures with temperature data from the Christchurch Airport provided the basis for linear regression analysis. Data from the Airport were used to predict the temperatures beyond the study period. The sites were assigned GDD and chill unit values according to the measured and extrapolated temperatures. Maps of GDDs and chill units were constructed using linear interpolation and subjective analysis. Frost occurrence was established from the minimum temperature data, and a map of frost risk was constructed.

Wind data were collected in the upper part of the valley for a six month period. The data were presented as a series of three hourly wind roses for the summer

and winter months and were compared to data from the Bromley and Christchurch Airport sites. This gave an indication of the modifying effect of topography on the gradient and mesoscale winds, and enabled the thermotopographically generated winds in the valley to be identified. Three case studies of a temperature inversion, the normal lapse rate and a severe frost in gave insight into the synoptic controls on the minimum temperature distribution. These included such factors as the wind direction and speed, cloud cover and atmospheric stability.

Published knowledge of the climatic requirements of selected crops was used to evaluate their suitability to the Horotane Valley microclimate. The research has shown that the valley climate could support other marginal crops such as grapes and kiwifruit, and the area planted in stonefruit could be extended up the valley slopes.

Future research

The research was limited by a sparse network of maximum/minimum thermometers. Queries raised about the temperatures between the sites during the mapping of GDDs and chill units could have been answered with a denser network of thermometers. With the lack of continuously logging temperature data at each site, chill units had to be derived from linear interpolation between maximum and minimum temperatures. This did not give a truly representative chill unit value as hourly temperatures do not increase and decrease linearly. In addition, the limited time available for data collection meant that results are representative of the microclimate between February and June. Prediction of the temperature data from regression analysis with the Christchurch Airport, meant that the temperatures were only an approximation based on the trends in the data over the limited study period.

The wind data was collected in the upper part of the valley. Although this enabled the monitoring of thermotopographic wind development and general conclusions to be drawn about the spatial and temporal differences in the wind regime, additional monitoring in the lower valley would provide a more

comprehensive coverage of winds throughout the valley system. In particular it is of interest to know how the built up road at the end of the valley contributes to cold air ponding on the valley floor.

This research used a combination of linear interpolation and subjective analysis to construct contour maps of GDDs, chill units and frosts. The data could be incorporated into a Geographic Information System (GIS). Maps of the radiation regime, soil and slope characteristics could also be incorporated into the database. This would provide a flexible database from which site suitability for land-use can be determined by automated matching of the crop requirements to the climate and soil characteristics of the valley.

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Appendix

1A - SOIL LIMITATIONS FOR PASTORAL USE

(Source: Gibbs, 1968)

Class 1

Soils of gently undulating and rolling land with slight limitations for pastoral use

1A Limitations of nutrients

Heathcote silt loam

1B Limitations of drainage and nutrients

Horotane silt loam

Class 2

Soils of gently undulating and rolling land with moderate limitations for pastoral use

2A Limitations of insufficient moisture and, to a lesser extent, nutrients

Takahe silt loam

Class 3

Soils of gently undulating and rolling with severe limitations for pastoral use - not present in Horotane Valley

Class 4

Soils of hilly and steep land with slight to moderate limitations for pastoral use

Limitations of nutrients

Clifton hill soils

Class 5

Soils of hilly and steep land with moderate to severe soil limitations for pastoral use

5A Limitations of insufficient moisture

Takahe hill soils

Cashmere hill soils

Kiwi hill soils

Evans steepeland soils

Scarborough hill soils

5B Limitations of erosion and insufficient moisture

Takahe hill soils, eroded phase

Kiwi hill soils, eroded phase

Clifton hill soils, eroded phase

Scarborough hill soils, eroded phase

1-B CLASSIFICATION OF SOILS ACCORDING TO SOIL LIMITATIONS FOR URBAN LAND-USE

(Source: Trangmar and Cutler, 1983)

Class 1

Soils of flat to rolling land with minimal to slight limitations- can be urban, drainage needed for Horotane soil

Heathcote silt loam

Horotane silt loam

Class 2

Soils of flat to rolling land with moderate limitations - potential for housing, planning for erosion needed.

Limitations of shallow or moderate depth to rock

Rapaki silt loam

Limitations of slight tunnel gully erosion

Takahe silt loam

Class 3

Soils of flat to rolling land with severe limitations -low density urban - need control of tunnel gully, recreation

Limitations of moderate or severe tunnel gully erosion

Takahe silt loam

Class 4

Soils of hilly land with moderate limitations-low density urban, carefully planning needed. Best left as pastoral.

Limitations of slope and shallow or moderate depth to rock

Cashmere hill soils

Rapaki hill soils

Limitations of slope with or without tunnel gully or mass movement erosion

Clifton hill soils

Kiwi hill soils

Scarborough hill soils

Takahe hill soils

Class 5 -should not be used for urban purposes, soil conservation purposes.

Soils of hilly and steep land with severe limitations*

Limitations of slope and shallow depth to rock

Evans Steepland soils *

Limitations rated as severe (Class 5) where >30% soil

APPENDIX 2 - A Correlation Matrix For Mean Temperatures

	CHCH	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8
SITE 1	0.95								
SITE 2	0.92	0.92							
SITE 3	0.89	0.87	0.87						
SITE 4	0.95	0.97	0.95	0.92					
SITE 5	0.86	0.86	0.81	0.90	0.91				
SITE 6	0.90	0.89	0.86	0.96	0.94	0.95			
SITE 7	0.86	0.83	0.80	0.88	0.9	0.93	0.90		
SITE 8	0.87	0.84	0.82	0.89	0.91	0.93	0.90	0.99	
SITE 9	0.87	0.84	0.84	0.91	0.91	0.98	0.94	0.93	0.95

2 - B Correlation Matrix for Minimum Temperatures

	CHCH	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8
SITE 1	0.80								
SITE 2	0.83	0.93							
SITE 3	0.49	0.45	0.59						
SITE 4	0.83	0.89	0.92	0.61					
SITE 5	0.74	0.74	0.82	0.70	0.94				
SITE 6	0.70	0.62	0.76	0.72	0.87	0.96			
SITE 7	0.67	0.53	0.69	0.67	0.82	0.91	0.97		
SITE 8	0.64	0.50	0.67	0.70	0.80	0.92	0.97	0.98	
SITE 9	0.70	0.59	0.75	0.74	0.85	0.95	0.99	0.95	0.98

2 - C Correlation Matrix for Maximum Temperature

	CHCH	SITE 1	SITE 2	SITE 3	SITE 4	SITE 5	SITE 6	SITE 7	SITE 8
SITE 1	0.97								
SITE 2	0.90	0.90							
SITE 3	0.97	0.97	0.90						
SITE 4	0.96	0.98	0.93	0.97					
SITE 5	0.95	0.97	0.82	0.96	0.95				
SITE 6	0.96	0.96	0.85	0.96	0.94	0.97			
SITE 7	0.95	0.96	0.83	0.96	0.94	0.98	0.97		
SITE 8	0.94	0.95	0.87	0.96	0.94	0.96	0.95	0.98	
SITE 9	0.96	0.97	0.89	0.98	0.96	0.96	0.96	0.98	0.99